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EVALUATION OF FRICTIONAL RESISTANCE OF CONVENTIONAL BRACKETS WITH DIFFERENT LIGATING METHODS AND DIFFERENT SELF-LIGATING BRACKETS

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DECLARATION

I declare that this thesis is a result of my own studies and there is no non-ethical act from the beginning to the end at any stage. All the information in this thesis is acquired in the borders of academical and ethical rules. The information and the comments mentioned that are not a part of my own study are referred and all the references are have a part in the reference list. During the study and writing of this thesis I did not have any prohibiting act on patent and copyright laws.

Rıdvan BAYRI

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LIST of CONTENTS

THESIS APPROVAL..... II
DECLARATION.....III
ACKNOWLEDGMENTS.....IV
LIST of CONTENTS.....V
LIST of TABLES.....IX
LIST of FIGURES.....XI
ABBREVIATIONS and SYMBOLS.....XIV
1. ÖZET.....1
2. ABSTRACT.....2
3. INTRODUCTION and AIM.....3
4. LITERATURE REVIEW.....5
4.1. Physical Factors Influencing Friction in Orthodontic Appliances….....8
4.1.1. Factors related to brackets ...……..……..….8
4.1.1.1. Effect of the bracket material and manufacturing process……,…8
4.1.1.2. Effect of bracket design and slot size……..…….10
4.1.1.3. Surface roughness……..14
4.1.2. Factors related to the arch wire…….....15
4.1.2.1. Wire material ……..……15
4.1.2.2. Cross-sectional shape and size of the wire……..……18
4.1.2.3. Surface texture……...……20
4.1.2.4. Stiffness……...…….....20
4.1.3. Ligation technique of the arch wire to the bracket……..……..21
4.1.4. Orthodontic appliance……..…….....23
4.1.4.1. Inter bracket distance…….……...23
4.1.4.2. The point of applied force for retraction…….……23
4.1.4.3. Sliding velocity…….24
4.2. Biological Factors Influencing Friction in Orthodontic Appliances.....24
4.2.1. Saliva……..……...24
4.2.2. Vibration…….....25
4.2.3.Corrosion……....……..26

5. MATERIALS AND METHOD……..……27

5.1. Materials……...…….27

5.1.1. Brackets ……...……27

5.1.1.2. Conventional brackets…….…….27

5.1.1.3. Self ligating brackets…….…28

5.1.2. Arch wires…….....28

5.1.3. Ligating materials and methods…….29

5.1.4. The special designed jig and light cure adhesive……...29

5.2. Method……...…..31

5.2.1. Preparing the metal plates……...…...31

5.2.2. The transferring apparatus……...…..……...32

5.2.3. Preparing the test samples……...…..…….32

5.2.4. Test procedures and measuring the frictional forces……...…….32

5.2.5. Statistical Analyses…….....35

6. RESULTS ……36

6.1. Crowded Configuration…….....36

6.1.1. Evaluation of frictional forces of the bracket brands according to the ligation methods at the crowded configuration…….....36

6.1.1.1. GAC elastomeric ligature method……...……...…38

6.1.1.2. Leone Slide ligature method…….....39

6.1.1.3. Metal ligature method…….....40

6.1.1.4. Self ligating brackets……41

6.1.2. Evaluation of mean frictional forces of three different ligation methods free of bracket brands at the crowded configuration…...….42

6.1.3. Evaluation of the mean frictional values of ligation methods in accordance with bracket brands at the crowded configuration……..44

6.1.3.1. Leone Logic Line ……...…..45

6.1.3.2. Inspire ICE……46

6.1.3.3. RMO Mini Taurus……...……....47

6.1.3.4. RMO Signature lll……...……...…..48

6.1.4. Evaluation of frictional values of self ligating brackets and conventional brackets ligated with different ligation methods at the crowded configuration ……...……..50

6.1.4.1 Self-ligating brackets and conventional brackets ligated with GAC elastomeric ligatures……...…..……...50
6.1.4.2. Self ligating brackets and conventional brackets ligated with Leone Slide ligatures……..……..54
6.1.4.3. Self ligating brackets and conventional brackets ligated with metal ligatures…….…….…..58
6.2. Aligned Configuration……..…….…….....……61
6.2.1. Evaluation of frictional forces of the bracket brands according to the ligation methods at the aligned configuration…….…....61
6.2.1.1. GAC elastomeric ligature method……..…….....63
6.2.1.2. Leone Slide ligature method…….……...……64
6.2.1.3. Metal ligature method……...…65
6.2.1.4. Self ligating brackets……66
6.2.2. Evaluation of mean frictional forces of three different ligation methods free of bracket brands at the aligned configuration……..67
6.2.3. Evaluation of the mean frictional values of ligation methods in accordance with the bracket brands at the aligned configuration…..69
6.2.3.1. Leone Logic Line…….....70
6.2.3.2. Inspire ICE…...…….....71
6.2.3.3. RMO Mini Taurus …….....72
6.2.3.4. RMO Signature lll…….....73
6.2.4. Evaluation of frictional values of self ligating brackets and conventional brackets ligated with different ligation methods at the aligned configuration ……..74
6.2.4.1. Self ligating brackets and conventional brackets ligated with GAC elastomeric ligatures……..…..75
6.2.4.2. Self ligating brackets and conventional brackets ligated with Leone Slide ligatures……..……...79
6.2.4.3. Self ligating brackets and conventional brackets ligated with metal ligatures……....83
7. DISCUSSION…….…….86
7.1. Purpose ……...……86
7.2. Materials and Method……...…86

7.3. Results……..92
7.3.1. Comparison of frictional values of different ligation methods free of bracket brands ……92
7.3.2. Comparison of the frictional values of conventional brackets ligated with different ligation methods…….....94
7.3.2.1. GAC elastomeric ligature…….....94
7.3.2.2. Metal ligature…….....95
7.3.2.3. Slide ligature…….....97
7.3.3. Comparison of the frictional values of self ligating brackets ……..98
7.3.4. Comparison of the frictional values of the self ligating brackets and conventional brackets ligated with GAC elastomeric and metal ligatures…….....99
7.3.4.1. GAC elastomeric ligature……...99
7.3.4.2. Metal ligature…….....100
7.3.5. Discussion of the frictional values of the self ligating brackets and nonconventionally (Leone Slide ligatures) ligated conventional brackets…….....102
8. CONCLUSION…….....104
9. REFERENCES…….....106
10. BIOGRAPHY ……114

LIST of TABLES

Table 1. Variables affecting frictional resistance in orthodontic sliding Mechanics ……..……7

Table 2. Evaluation of frictional forces of the bracket brands according to the ligation methods (crowded configuration)……..36

Table 3. Evaluation of frictional forces of bracket brands with different ligation methods in couple comparison by using Tukey test (crowded configuration)…….37

Table 4. Evaluation of frictional forces of self ligating brackets in couple comparison (crowded configuration)……..…41

Table 5. Evaluation of mean frictional forces of three different ligation methods (crowded configuration)…….…….....42

Table 6. Evaluation of frictional forces of ligation methods in couple comparison (crowded configuration)…….…42

Table 7. Evaluation of the mean frictional values of ligation methods in accordance with bracket brands (crowded configuration)……..44

Table 8. Evaluation of frictional forces of ligation methods in couple comparison by using Tukey test on different bracket brands…….44

Table 9. Comparison of frictional values of self ligating / conventional brackets ligated with GAC elastic ligatures……..49

Table 10. Comparison of frictional values of self ligating brackets and conventional brackets ligated with Leone Slide ligatures (crowded configuration)……..53

Table 11. Comparison of frictional values of self ligating brackets and conventional brackets ligated with metal ligatures……..57

Table 12. Evaluation of frictional forces of the bracket brands according to the ligation methods (aligned configuration)…….….61

Table 13. Evaluation of frictional forces of bracket brands in couple comparison with different ligation methods by using Tukey tests

(aligned configuration)……..……..62
Table 14. Evaluation of frictional forces of self ligating brackets in couple comparison (aligned configuration)……....66
Table 15. Evaluation of the mean frictional forces of different ligation methods (aligned configuration)…….…67
Table 16. Evaluation of frictional forces of ligation methods in couple comparison (aligned configuration)…….67
Table 17. Evaluation of the mean frictional values of ligation methods in accordance with the bracket brands (aligned configuration)……69
Table 18. Evaluation of frictional forces of ligation methods in couple comparison by using Tukey test on different bracket brands…...68
Table 19. Comparison of frictional values of self ligating brackets and conventional brackets ligated with GAC elastic ligatures. (aligned configuration)…….....74
Table 20. Comparison of frictional values of self ligating brackets and conventional brackets ligated with Leone Slide ligatures (aligned configuration)……..78
Tablo 21. Comparison of frictional values of self ligating brackets and conventional brackets ligated with metal ligatures……...……..…82

LIST of FIGURES

Figure 1. Frictional values of conventional brackets ligated with GAC elastomeric ligatures at the crowded configuration…….....……38

Figure 2. Frictional values of conventional brackets ligated with Leone Slide ligatures at the crowded configuration…….…..……..39

Figure 3. Frictional values of conventional brackets ligated with metal ligatures at the crowded configuration ……40

Figure 4. Frictional values of self-ligating brackets at the crowded configuration.41

Figure 5. Frictional values of ligating methods free of bracket brands at the crowded configuration……..……43

Figure 6. Frictional values of ligation methods in accordance with Leone Logic Line brackets at the crowded configuration .....……45

Figure 7. Frictional values of ligation methods in accordance with Inspire ICE brackets at the crowded configuration ....……...…….46

Figure 8. Frictional values of ligation methods in accordance with RMO Mini Taurus brackets at the crowded configuration .....…….….....47

Figure 9. Frictional values of ligation methods in accordance with RMO Signature lll brackets at the crowded configuration……48

Figure 10. Frictional values of Clarity SL and conventional brackets ligated with GAC elastomeric ligatures……...……..…50

Figure 11. Frictional values of Damon 3 and conventional brackets ligated with GAC elastomeric ligatures……...……..…51

Figure 12. Frictional values of Innovation C and conventional brackets ligated with GAC elastomeric ligatures…….52

Figure 13. Frictional values of Clarity SL and conventional brackets ligated with Leone Slide ligatures……..54

Figure 14. Frictional values of Damon 3 and conventional brackets ligated with Leone Slide ligatures……..55

Figure 15. Frictional values of Innovation C and conventional brackets ligated with Leone Slide ligatures……...…….56

Figure 16. Frictional values of Clarity SL and conventional brackets ligated with metal ligatures……...…….58
Figure 17. Frictional values of Damon 3 and conventional brackets ligated with metal ligatures……59
Figure 18. Frictional values of Damon 3 and conventional brackets ligated with GAC elastomeric ligatures…….60
Figure 19. Frictional values of conventional brackets ligated with GAC elastomeric ligatures at the aligned configuration**.....**…….…63
Figure 20. Frictional values of conventional brackets ligated with Leone Slide ligatures at the aligned configuration…….…..……..64
Figure 21. Frictional values of conventional brackets ligated with metal ligatures at the aligned configuration ……..……..65
Figure 22. Frictional values of self-ligating brackets at the aligned configuration……..66
Figure 23. Frictional values of ligating methods free of bracket brands at the aligned configuration……...……..…….....68
Figure 24. Frictional values of ligation methods in accordance with Leone Logic Line brackets at the aligned configuration **.....**……..70
Figure 25. Frictional values of ligation methods in accordance with Inspire ICE brackets at the aligned configuration ...……...……..71
Figure 26. Frictional values of ligation methods in accordance with RMO Mini Taurus brackets at the aligned configuration .....…….....72
Figure 27. Frictional values of ligation methods in accordance with RMO Signature lll brackets at the aligned configuration……..……73
Figure 28. Frictional values of Clarity SL and conventional brackets ligated with GAC elastomeric ligatures……...……..…75
Figure 29. Frictional values of Damon 3 and conventional brackets ligated with GAC elastomeric ligatures……...……..…76
Figure 30. Frictional values of Innovation C and conventional brackets ligated with GAC elastomeric ligatures…….……77
Figure 31. Frictional values of Clarity SL and conventional brackets ligated with Leone Slide ligatures……..79

Figure 32. Frictional values of Damon 3 and conventional brackets ligated with Leone Slide ligatures……..……..80

Figure 33. Frictional values of Innovation C and conventional brackets ligated with Leone Slide ligatures……...……...…81

Figure 34. Frictional values of Clarity SL and conventional brackets ligated with metal ligatures……...…….83

Figure 35. Frictional values of Damon 3 and conventional brackets ligated with metal ligatures……84

Figure 36. Frictional values of Damon 3 and conventional brackets ligated with GAC elastomeric ligatures……..……...….85

LIST of PICTURES

Picture 1. Jig for the crowded configuration……..……...30
Picture 2. Jig for the aligned configuration……..……...……..30
Picture 3. Leone Slide Ligatures……..……...……..…30
Picture 4. GAC elastomeric ligatures…….……..30
Picture 5. Brackets (RMO Mini Taurus, Inspire ICE, Leone Logic Line, RMO Signature lll, Clarity SL, Damon 3, Innovation C)…….……..…30
Picture 6. Brackets at the crowded configuration (side view)…….……..…34
Picture 7. Brackets at the crowded configuration (upper view)……..…….34
Picture 8. Transferring apparatus and 200gr weight……..……...34
Picture 9. Fixed Stainless steel plates to the testing machine……...34
Picture 10. Brackets at the aligned configuration……..……...34
Picture 11. Zwick/roell testing machine……..…….34
Picture 12. Stainless steel plate before fixing to the transferring apparatus…….....34

ABBREVIATIONS and SYMBOLS

Ni-Ti: Nickel Titanium

SS: Stainless Steel

N: Newton

g: Gram

SEM: Scanning Elektron Microscope

“: Inch

et al: And friends

mm: milimeters

Co-Cr: Cobalt-Chromium

1. SUMMARY

The aim of this study was to investigate three different brands of esthetic self ligating brackets in terms of friction and compare them to the brackets ligated conventionally and non-conventionally. Self ligating brackets were Damon 3, Clarity SL and Innovation C whereas conventional brackets were Signature lll, Logic Line, Inspire ICE and Mini Taurus. Conventional brackets were ligated with metal ligatures, elastomeric Ligatures and Slide ligatures. There were two configurations for bracket alignments, one was mimicking the initial phase of the treatment and the other was mimicking the post leveling phase. At the first configuration, to represent right upper quadrant of a patient 5 brackets, starting from the central incisor to the second premolar were aligned in a way that canine bracket was 2 mm superior and 2 mm out of the arch and 0,014“ nickel titanium arch wires were used to perform the friction tests. Whereas at the second configuration, brackets were placed in a leveled position and 0,016” stainless steel arch wires were used. Special designed jigs made of 0,017”x 0,025” stainless steel were used to standardize the bracket configurations. Inter bracket distance were set 8,5 mm and all testing procedures were done in dry conditions and at the room temperature. The testing apparatus were Zwick/Roell testing machine. Passive self ligating brackets and Logic Line brackets ligated with Slide ligatures showed the least frictional resistances. Slide ligation method showed significantly lower frictional levels compared to conventional methods. Inspire ICE brackets showed the highest frictional resistance.

Key words: Esthetic brackets, Friction, Ligation method, Self ligating brackets, Slide ligatures

2.ÖZET

Kendinden Bağlamalı Braketlerin ve Farklı Yöntemlerle Bağlanmış Konvansiyonel Braketlerin Sürtünme Dirençlerinin Değerlendirilmesi

Bu çalışmanın amacı üç farklı estetik kendinden bağlamalı braketin sürtünme özelliklerini incelemek ve bu braketleri konvansiyonel ve konvansiyonel olmayan metodlarla bağlanmış braketlerle kıyaslamaktır. Çalışmada test edilen estetik kendinden bağlamalı braketler Damon 3 (SDS Ormco), Clarity SL (3M Unitek) ve Innovation C (GAC), estetik konvansiyonel braketler ise Signature lll (RMO), Logic Line (Leone) ve Inspire ICE (Ormco) olup metal konvansiyonel braket Mini Taurus (RMO) tur. Konvansiyonel braketler metal ligatür, elastomerik ligatür (GAC) ve Slide (Leone) ligatürlerle bağlanarak sürtünme deneyleri gerçekleştirilmiştir. Çalışmanın düzeneği oluşturulurken tedavinin başlangıç ve seviyelenme sonrası aşamalarını taklit etmek üzere iki farklı braket dizilimi yapılmıştır. Birinci dizilimde hastanın sağ üst santral-ikinci küçük azı arası bölgesini temsilen her marka için beş braket, kanin braketi 2 mm yukarıda ve ark dışında kalacak şekilde çarpraşık, ikinci dizilimde ise braketler seviyelenmiş durumda kompozit yapıştırıcılar kullanılarak metal plakalar üzerine dizilmiştir. Çarpraşık dizilimde deneyler için 0,014" Ni-Ti, ikinci dizilimde 0.016" SS ark telleri kullanılmıştır. Her iki dizilimde farklı markalar arasında aynı standardizasyonu sağlayabilmek için 0,017"x0,025" paslanmaz çelik telden özel dizayn edilmiş jigler kullanılmıştır. Braketler arası mesafe 8,5 mm olarak ayarlanmış ve deneyler oda sıcaklığında ve kuru ortamda yapılmıştır. Sürtünme kuvvetleri Zwick/Roell test cihazıyla ölçülmüştür. Pasif kendinden bağlamalı braketlerin ve Slide ligature ile bağlanan Logic Line braketlerin en düşük sürtünme direncini gösterdiği bulunmuştur. Slide Ligatür bağlama yöntemi anlamlı olarak konvansiyonel bağlama yöntemlerinden düşük sürtünme kuvveti oluşturmuştur. Inspire ICE braketler en yüksek sürtünme direncini göstermiştir.

Anahtar Kelimeler: Bağlama metodu, Estetik braketler, Kapaklı braketler, Slide ligature, Sürtünme

3. INTRODUCTION and AIM

Esthetic has become gradually one of the most important concerns among the society all over the world and there is no exception for orthodontic patients. They demand having a successful treatment meanwhile they are worried about their look with the brackets on. Considering these expectations, manufacturers have developed esthetic brackets made of materials such as ceramic, copolymer and composite.

But there were some disadvantages of these esthetic brackets. Studies with composite and ceramic brackets have shown that they caused more friction which can elongate the total treatment time. Friction is basically defined as "the resistance against the movement of two contacting bodies". Because of their body structures and surface characteristics, composite and ceramic brackets have higher friction co-efficient. They also cause abrasion at the arch wire which is an additional factor to increase the resistance against sliding. Other disadvantages can be counted as the need of using metal or teflon coated ligature wires which are not as esthetic and can cause discomfort to the patient. On the other hand clear elastomeric ligatures can be used but they increase the friction and they get discolored (yellowish) in a short while which contradicts the esthetic needs of the patient.

Tooth movement with fixed orthodontic appliances is generally accomplished by two methods: movement of teeth with the wire as in the segmented technique or along the arch wire as in the sliding mechanics with continuous wire. The main factor which distinguishes sliding mechanics from closing loop mechanics is, the production of frictional forces at the bracket-arch wire interface as the bracketed tooth is moved along the wire. Orthodontic forces should overcome these frictional forces to be able to move a tooth, however heavy forces have some other disadvantages like causing to loose anchorage or root resorbtion. So it would be favorable to minimize the frictional forces and at the same time respond to the esthetic needs of the patients. Manufacturers have developed self ligating esthetic brackets to answer this demand. They claimed that these brackets are both esthetic and low friction at the same time, even though it seems to be a contradiction.

Self ligating brackets have been developed to be an alternative to the conventional brackets, offering decreased chair time and total treatment time besides they propose smoother, more hygienic and more comfortable feeling for the patient

since they do not need to be ligated with wires or elastomerics.

In the literature, there have been many investigations about frictional forces of self ligating metal brackets. However the documents about the esthetic self-ligating brackets are very limited since they are comparably new on the market. They are not well acknowledged and thoroughly experienced among the orthodontists and additional detailed clinical and laboratory studies have not found enough place in the orthodontic field yet. The claim of the manufacturers is that esthetic self-ligating brackets are going to have some advantages in frictional features and patient comfort as well.

So we aimed to compare the frictional resistance of different brands of esthetic self ligating brackets to the conventional esthetic and metal brackets ligated with different methods at different stages of the treatment.

4. LITERATURE REVIEW

In today's orthodontics, sliding mechanics are widely used in which the teeth are forced to slide along the arch wires. Whilst the teeth are sliding there will be a friction force in the opposite direction of the movement. Consequently this friction force will be affecting the biology, the results and the total treatment time.

Studies have shown that in optimum arch wire and bracket combinations, up to 60 percent of applied force is lost because of friction, which means, orthodontists need to apply extra force to be able to move the teeth. However this brings disadvantages both in anchorage control and in biological manner. Optimum orthodontic force is defined as having the maximum biologic response and movement of teeth while minimizing tissue harm. As a general rule, higher forces have higher potential for tissue damages.

Friction is the force that retards or resists the relative motion of two objects in contact. The direction of friction is tangential to the common boundary of the two surfaces in contact. As two surfaces in contact slide against each other, two components of total force arise: the frictional component (F) is parallel but in opposite direction to the sliding motion, and the normal force (N) is perpendicular to the contacting surfaces and to the frictional force component. Frictional force is directly proportional to the normal force, such that F= p.N, where p=coefficient of friction.

During tooth movement, many factors exists that influence method using sliding mechanics for translating a tooth or a group of teeth during leveling, overjet reduction or space closure. The major disadvantage with the use of sliding mechanics is the friction that is generated between the bracket and the arch wire during orthodontic tooth movement. Friction is a clinical challenge particularly with sliding mechanics and must be dealt with efficiently to provide optimal orthodontic results.

The amount of friction is proportional to the force with which the two surfaces are pressed together and dependent on the nature of the surfaces in contact (composition of the material, surface roughness, etc.). The force applied, therefore, has to overcome friction to achieve the desired orthodontic movement.

There are two types of friction: static friction and kinetic or dynamic friction;

Static friction presents the resistance to initial motion, whereas kinetic friction is the force required to maintain motion. Common observations have demonstrated that the static frictional force is greater than the dynamic frictional force. Thus the same relationship exists for the coefficients of static friction and dynamic friction.

The static frictional force is the smallest force needed to start the motion of solid surfaces that were previously at rest with each other, whereas the kinetic frictional force is the force that resists the sliding motion of one solid object over another at a constant speed (75). The coefficient of friction has a value that is between zero and one. Its magnitude is dependent mainly on the nature of the materials in contact.

Problems of loss of applied force due to friction during sliding mechanics have been recognized for a long time. The portion of the applied force lost due to the resistance to sliding can range from 12% to 60% (63). If frictional forces are high, the efficiency of the system is affected and the treatment time may be extended or the outcome may be compromised because of little or no tooth movement and/or loss of anchorage (22, 41, 20, 24).

The phenomenon of friction is multi factorial. The orthodontic literature demonstrates numerous variables that affect the levels of friction between the bracket and arch wire. Resistance during tooth movement may be due to physical or biological parameters. Physical parameters include material and design of the bracket, bracket width and slot size, inter bracket width, arch wire type, arch wire size and shape, the ligation technique, second order angulations, and sliding velocity. Biological considerations are saliva, plaque and corrosion. In addition, experimental protocol and design often affect the outcome of in-vitro frictional studies.

Variables affecting friction in orthodontics were summarized by Nanda in the following table. Literature review will be documented accordingly.

Table 1. Variables affecting frictional resistance in orthodontic sliding mechanics

A. PHYSICAL

1. Bracket

- Material and Manufacturing Process
- Bracket Design and Slot Size
- Surface Roughness

2. Arch wire

- Material
- Cross-Sectional Shape/Size
- Surface Texture
- Stiffness

3. Ligation technique of the arch wire to the bracket

4. Orthodontic Appliance

- Inter Bracket Distance
- The point of applied force for retraction
- Sliding Velocity

B. BIOLOGICAL

- Saliva
- Vibration
- Corrosion

4.1. Physical Factors Influencing Friction in Orthodontic Appliances

4.1.1. Factors related to brackets

4.1.1.1. Effect of the bracket material and manufacturing process

The two main categories of brackets are metal brackets and esthetic brackets. Metal brackets are currently manufactured from stainless steel, chromium-cobalt and titanium. Stainless steel brackets are usually produced from type 300 stainless steels and can be further distinguished as either sintered or cast according to their manufacturing process. The esthetic brackets can be subdivided into alumina ceramic brackets, zirconium oxide (zirconia) ceramic brackets and ceramic-reinforced composite brackets.

The alumina brackets are further distinguished by their crystalline structure as either polycrystalline or mono crystalline as well as by their manufacturing process as either sintered or injection molded. Some of the composite and ceramic brackets also have metal slots.

The majority of studies reported that stainless steel brackets had decreased friction compared to ceramic brackets. Some investigators attributed this to the increased roughness of ceramic brackets, while others attributed it to the chemical structure of ceramic brackets. Taylor NG and Ison K (110) in 1991, however, produced different results. Ceramic reinforced composite brackets produced less friction than stainless steel brackets and ceramic-reinforced composite brackets with metal slots when the 0.018 inch slot size was investigated. When 0.022 inch slot brackets were tested however, ceramic-reinforced brackets with metal slots and stainless steel brackets were associated with the lesser friction. In another study Kusy and Whitley, found no significant difference between stainless steel and polycrystalline ceramic brackets (54). With respect to esthetic brackets, composite brackets demonstrated less friction than ceramic brackets, and single crystal alumina brackets tended to have less friction than polycrystalline alumina brackets. Zirconium oxide brackets were found to have variable friction relative to polycrystalline alumina brackets. Although the above studies indicated that different brackets had different frictional resistances, some researchers such as Keith and Hixon (46) found that bracket material did not influence friction as much as arch wire material. On the other

hand injection molded ceramic brackets appeared to be smoother than sintered ceramic brackets and this may have accounted for the decreased function of injection molded brackets.

For reasons of esthetics and biocompatibility issues, more recently newer materials have been investigated as alternatives to improve function performance. Stainless steel brackets have been shown by numerous investigators to have lower frictional forces than ceramic brackets (45, 8, 17). The suggestion is that metal brackets have smoother surfaces compared to ceramic brackets (59). Articolo et al (1999) found stainless steel brackets to have less friction than their ceramic counterparts in the passive configuration, which agrees with the previous work (59, 3). However, in the active configuration, when resistance to sliding is the product of friction and binding, stainless steel brackets were less efficient than ceramic brackets.

Ceramic brackets have come into more common use because of their improved esthetics, but many problems are associated with their clinical use. In particular, ceramic brackets have higher coefficients of friction (59, 57) and greater frictional resistances (8, 37, 47). Under scanning electron microscopy, ceramic brackets display a crystalline structure containing many pores while stainless steel brackets slots are smoother with fewer irregularities (20). This rougher surface finish of the ceramic bracket slots has been implicated as the reason for the higher frictional force (82, 118, 47).

Using a full dimension wire with straight-line traction, ceramic brackets observed to cause abrasive wear of the arch wire. Kusy and Whitley (1991) suggested that the behavior of ceramic brackets might be because of their intrinsic chemical structure rather than the roughness (57). Of the ceramic brackets, De Franco et al (1995) found single crystal alumina brackets tended to be lower in friction than polycrystalline brackets (17). Saunders and Kusy (1994) showed by scanning electron microscopy that mono crystalline alumina brackets to be smoother than polycrystalline brackets, but found no difference in frictional characteristics (96). On the other hand, Omana et al (1992) stated that the polycrystalline injection molded ceramic brackets were smoother and this created less friction than other ceramic brackets (75). To improve the sliding performance of ceramic brackets, metal inserts have been placed in the slots to reduce friction. Loftus et al (1999) found that Clarity ceramic brackets with a metal slot insert (Unitek Corp., Monrovia, CA) have the same results as well as conventional stainless steel brackets in friction tests. Plastic

brackets have shown higher frictional resistances than stainless steel brackets (89,112) however Riley suggested this resulted from deformation of the plastic brackets due to tightening of the steel ligatures that lead to compression of the slot and binding of the wire. Recently introduced composite brackets with and without metal slots faired better in friction studies. Bazakidou et al (1997) found these newer composite brackets to have lower frictional resistance than both ceramic and stainless steel brackets (7). Additionally, with regards to repeated in-vitro friction testing of the same orthodontic bracket a distinct trend for an increase in the mean frictional force was found regardless of material type.

The manufacturing process and bracket design may also influence the frictional characteristics of orthodontic brackets. Recent investigations found that sintered stainless steel brackets reduced friction by as much as 40 to 45% relative to cast stainless steel bracket. This was attributed to the sintering process resulting in smooth, rounded corners, whereas cast brackets had sharper edges resulting from the milling or cutting process. Vaughan et al 1995 compared sintered stainless steel brackets to the cast stainless steel brackets (114). They found sintered brackets have reduced friction and when they investigated brackets surfaces with SEM and they found out that sintered brackets have smoother surface structure than cast brackets. So they related the decreased friction values of sintered brackets to its surface smoothness.

4.1.1.2. Effect of bracket design and slot size

The basic premise behind the design of orthodontic brackets is that a slot allows ligation of a wire to control movement of a tooth in some desired direction. However, no standard design exists, but some designs have been advocated to assist in reduction of friction. Ogata et al (1996) found that bracket designs, which restricted the amount of force placed on the wire by the ligature, generated lower frictional forces. An example is the Synergy bracket (RMO, Denver, CO) that has six tie-wings for variable ligation (76). Ligation of only the center wings limits the force of the ligature on the wire. Therefore, the normal force can be markedly reduced.

In another example, Kuroe et al (1994) claimed that the design of Friction Free brackets (American Orthodontics, Sheboygan,WI) prevented ligature wires or elastomers from exerting their force on the arch wire , and hence there is virtually no vertical load of the arch wire on the bracket (52). These Friction Free brackets were

found to have considerably less frictional resistance during straight line traction than conventional edgewise stainless steel brackets

Thomas et al (1998) and Kapur et al (1998) found that self-ligating brackets produced less friction than elastomerically-tied conventional edgewise brackets. These self-ligating brackets tested did not exert pressure on the arch wires (111,42). Sims et al (1993) also found that self-ligating brackets had less frictional resistance than conventionally tied brackets (100). In addition, Sims et al (1993) noted that self-ligating brackets without an active spring clip had about fifteen times less frictional resistance than self-ligating brackets with an active spring clip.

Using a buccal segment model, Taylor and Ison (1991) reported similar findings with passive self-ligating brackets (110). The brackets had significantly less frictional resistance than self-ligating brackets with an active spring-clip and conventionally tied brackets. All of these investigations were done with static straight line traction that was not subjected to change in second order angulation. Sims et a1 (1994) later reported that increasing angulation had a more profound effect on self-ligating brackets than conventional brackets, but they still produced less friction. Pizzoni et al (1998) reported similar results (101,80).

Pizzoni et al (1998) found self ligating brackets to have less friction at all angulations than conventional brackets (80). He also noted that self-ligating brackets that closed by capping of the wire slot exhibited significantly lower friction than those of closed by a spring. Read-Ward et al (1997) investigated various self-ligating brackets compared to conventional brackets. Results suggested self-ligating brackets had lower frictional resistance in the passive configuration, but frictional resistance increased for the self-ligating brackets as second order angulation increased such that they were comparable to conventional brackets (87).

Shivapuja and Berger (1994) found self-ligating brackets with both active and passive spring clips displayed significantly lower level of friction than conventional stainless steel and ceramic brackets (99). In contrast, Bednar et al (1991) testing self-ligating brackets with an active spring clip and Loftus et al (1999) testing self-ligating brackets with a passive spring clip found these bracket types performed no better than conventional stainless steel brackets ligated by either elastomers or steel ties in friction tests using an approximated center of resistance that permitted free second order tipping (8).

As for the effect of slot size, most investigators have found slot size to have no

influence on frictional resistance (58,113). However, studies by Andreas and Quevedo (1970) and Rock and Wilson (1989) suggested that frictional resistance decreased as slot size jumped from 0.018 inch to 0.022 inch due to reduced binding probably from increased wire stiffness (1,80). Based on a mathematical model, Kusy and Whitley (1999) suggested that smaller bracket dots compared to larger bracket dots may cause more binding to occur if the initial alignment and leveling are not precise enough (65).

Kapilla tested SS, Co-Cr, Ni-Ti and Beta-Titanium wires with 0.018 and 0.022 SS brackets and conclude that brackets having 0.022 slots have showed lower friction values but there is no conclusive evidence that slot size significantly affects frictional resistance to sliding at the arch wire-bracket interface (41). More importantly, the size of the arch wire relative to the slot size has a greater impact on frictional resistance. So as the wire size increases, the wire occupies more of the slot leading to greater fiction

There are conflicting results as to the effect of bracket width on frictional resistance. Part of the discrepancy is derived from differences in experimental protocol. Studies that do not allow changes in the second order angulation of the bracket relative to the arch wire typically demonstrate that bracket width and inter bracket distance have an insignificant effect on frictional resistance compared to variables such as ligation force and arch wire or bracket surface characteristics (1.79). Studies that allow for changes in second order angulations produce binding at the arch wire-bracket interface contributing to the frictional resistance that is summarily affected by bracket width, inter bracket width, and flexural stiffness of the arch wire. (98).

Arguments have been made that implicate wider brackets as the cause of greater friction at small non-binding angulations. Two main reasons have been set to explain this. Kapila et al (1990) attributed the increase in friction with wider brackets to larger normal forces created by greater stretching of the elastomeric ligature over the wider brackets (41). Frank and Nikolai (1980) felt the reason for more friction with the wider brackets was derived from a larger contact surface area of the wire with the wider bracket (28). Second order binding angulations that restrict the amount of tipping have shown that narrower brackets produce less friction than wider brackets.

This was ascribed to the narrower brackets having less binding than the wider

brackets (28). Similarly, Yamaguchi et al (1996) found that if the location of force application for retraction was closer to the center of resistance which controlled the amount of tipping the angulation of the arch wire to the bracket would be less with a narrow bracket compared to a wider bracket, and hence resulted in a lower retraction force, meaning there was less friction (119).

When second order angulation is not restricted the bracket width has a different effect on friction results. Under these conditions, wider brackets have been reported to produce less friction than narrow brackets by allowing less angulation change of the arch wire, and hence less binding (22, 113, 75, 101). It was reported that greater tipping occurs with narrower brackets (22), thus leading to a more acute angle of interface between the bracket and the arch wire (75).

Yamaguchi et al (1996) also found that when a retracting force was applied at the level of the bracket unrestricted tipping occurred causing a greater angulation between the bracket and the arch wire for narrower brackets than wider brackets. This led to a significantly higher force of retraction for the narrower bracket than the wider bracket because of the increased attendant friction (119). However, the width of the bracket alone cannot simply account for the level of friction encountered because a complex relationship exists between the bracket widths, inter

bracket distance, and wire stiffness, with these variables having a significant effect on frictional forces (98).

First of all, an inverse relationship exists between the bracket width and inter bracket distance. So as bracket width decreases, inter bracket distance increases. The increased inter bracket distance increases wire flexibility and thereby decreases the resultant frictional force from second-order binding. With this in mind, Moore and Waters (1993) demonstrated that the restoring couple of a bracket varies with the bracket width and the inter bracket distance, leading to the conclusion that wider brackets have inherently less friction based on a simple beam theory (71). Most likely then, if the retraction forces are not too high, then wider brackets may offer less friction owing to less tipping and hence less binding of the bracket with the arch wire (71). Omano et al (1992) stated that higher retraction forces may negate the mechanical advantage of the wider brackets and lead to more friction (75).

However, Schegel (1996) felt that the analysis by Moore and Waters was not valid because it considered only one bracket and did not take into consideration that

the ends of the beams would be rigidly fixed (98). Schlegel's (1996) biomechanical analysis demonstrated an ideal relationship exists between slot length, inter bracket distance, and position of the active bracket so that friction effects would be minimized. The analysis concluded that claims advocating the use of the widest bracket or the narrowest bracket were false. This intuitively suggests that an "average" width bracket would be more optimal, although Schlegel (1996) did not state a size.

4.1.1.3. Surface roughness

Several investigators analyzed and compared the surface roughness of different orthodontic brackets using scanning electron microscopy. There was overall agreement that stainless steel brackets had smoother and less porous surfaces than ceramic brackets and that mono crystalline ceramic brackets had smoother surfaces than their polycrystalline counterparts (46, 83, 89). The influence of surface roughness on friction appeared variable since not all investigators found a positive correlation between surface roughness and frictional resistance. For example, a few investigators reported that ceramic brackets had decreased friction relative to stainless steel brackets and mono crystalline brackets had frictional levels similar to polycrystalline ceramic brackets (89, 110). Another study attributed the increased friction of ceramic brackets to their surface roughness since the ceramic brackets produced more arch wire damage than stainless steel brackets during sliding mechanics (62).

4.1.2. Factors related to the arch wire

4.1.2.1. Wire material

Arch wire material has a great influence on frictional resistance during sliding mechanics. In the fields of orthodontics, arch wire materials can be classified mainly as below.

Stainless steel arch wires are most commonly used materials in orthodonthics. Stainless steel arch wires have high stiffness low working range and high durability characteristics. Thus they are not appropriate for leveling stages or need some extra loop designs in order to decrease stiffness.

Chromium-cobalt arch wires are more resistant against distortion and breakage

compared to stainless steel brackets. Their composition consist of %40 cobalt, %20 chromium, %15 nickel, % 7 molibden and %15-20 ferrum. They are produced in four different resilient levels which are soft (blue), ductile (yellow), half resilient (green) and resilient (red).

Nickel titanium arch wires were first introduced by Andreasen in the orthodontic field which has shape memory and super elasticity. They have more than one crystal structure related to heat of the environment. It shows martensite structure in lower degrees but austenite structure in higher degrees. Shape memory is the ability of the wire to remember its original shape when subjected to a plastic deformation in the martensite structure.

Super elasticity can be described that the wire showing the same stress level until a curtain point of deformation and keeping this value steady while returning to its original shape. Conventional nickel titanium wires are stabilized in the martensitik phase and shows no phase change.

Pseudo elastic type nickel titanium wires are active austenite structured wires. The structure of these wires can change from austenite to martensite phase related to mechanical stress .When the stress reached a curtain level during the activation of the arch wire, it becomes martensitic and when the stress decrease back they return to austenite phase. Pseudo elastic arch wires supplies longer, lighter and smoother forces compared to conventional nickel titanium arches.

Thermo elastic nickel titanium wires are martensite active wires. They are bendable in lower degrees and they become active austenite phase in the patient's mouth.

Composition of these wires consist of %79 titanium, %11 molybdenum, %6 zirconium and %4 zinc. They are bendable, high resistant and their stiffness is between the stainless steel and nickel titanium wires.

Studies showed that beta titanium wires have more surface roughness and more friction than the producers recently started to make ion implantation in order to increase surface hardness and decrease the friction.

Fiber optic wires, are developed with esthetic concerns and they are clear. Their stiffness is very low and they are fragile compared to other wires so that they are not commonly used in orthodontics yet.

Composite wires are one of the newest in the orthodontic field .They produced by covering a layer of composite on a fiber. Their stiffness is higher than the fiber

optic plastic wires but they are still weak against breakage.

Arch wire composition is a significant factor in determining the level of friction in an orthodontic appliance. Beta titanium and nickel titanium arch wires generally produced more friction than stainless steel and chromium cobalt arch wires.

Multi stranded rectangular stainless steel arch wires also produced less friction than rectangular nickel titanium and beta titanium arch wires regardless of the bracket arch wire angulations. Esthetic polyacetyl wires were also investigated and it was determined to be unacceptable for orthodontic purposes since it underwent considerable plastic deformation during the experimental process.

The functional coefficients of arch wires of different alloys against stainless steel or Polycrystalline alumina brackets has been shown to be titanium (highest), nickel-titanium, cobalt-chromium and stainless steel (lower). Garner et al (1986) felt that the frictional coefficient hierarchy observed was due to the surface roughness exhibited by the arch wire material (29). However, Kusy and Whitley (1988) demonstrated, using specular reflectance with laser spectroscopy, that the order of surface roughness is stainless steel (lowest), cobalt-chromium, beta- titanium and nickel-titanium (highest) (58). The increased frictional resistance generated by titanium appears paradoxical considering that it exhibits lower surface roughness than nickel-titanium. The explanation for this phenomenon is related to adhesion (cold-welding) involving the formation, destruction and reformation of metal- the titanium arch wire -metal bonds among particles of the titanium arch wire and the stainless steel brackets (59, 60).

These results are consistent with Prosoki et al. (1991) who also determined that "with intermediate ranges of surface roughness" there was no correlation between surface roughness and functional resistance (83). Kusy et al (1990) echoed this sentiment by stating that a significant correlation does not always exist between surface roughness and coefficients of friction in situations where surface chemistry and chemical affinity lead to adhesive or abrasive mechanisms (59, 60)

Burstone at al state that ion implanted beta titanium wires showing lower friction values than conventional beta titanium wires, and getting closer to those of stainless steel wires (13). Beta-titanium arch wires were showing higher frictional resistance than that of the stainless steel wires and nickel titanium wires. He also found no statistical significance difference between stainless steel and nickel titanium

arch wires. In all bracket arch wire combinations beta titanium arch wires showed the highest and stainless steel arch wires showed lowest frictional resistance and the frictional resistance of nickel titanium arch wires were in between them.

Kusy and Whitley (1999) stated that classical friction is the dominant factor controlling frictional resistance during sliding mechanics below a critical bracket arch wire contact angle. Once the critical contact angle is exceeded, binding and notching become the dominant variables determining functional resistance. Thus, studies whose designs are based on a straight line traction model are likely to differ significantly from those where tipping to the point of binding and notching occurs. Articolo at al found that as the stiffness of the arch wire increases, the frictional resistance is also increasing when the angulations between the arch wire and the bracket increased. At a passive configuration, stainless steel wires showed the lowest friction while beta titanium wires showed the highest however in active configuration stainless steel wires showed the highest friction because of its high stiffness.

4.1.2.2. Cross-sectional shape and size of the wire

Usually it is accepted that as the size of the wire increasing, the frictional force is also increased. However not all sequential increases in arch wire are resulted significantly in friction forces. Exceptions to the relationship between arch wire size and level of friction were noted. Among the nickel titanium wires, the largest rectangular wire displayed the least frictional resistance. Similarly, stainless steel arch wires demonstrated an inverse relationship between size and friction in ceramic brackets. This may have attributed to the increased bracket and arch wire contact with light wires secondary to the distortion of these lighter wires in the bracket slot as larger bracket-arch wire angulations were introduced. Furthermore, larger and stiffer wires had a decreased binding angle since they filled the slot more and this may have decreased friction. Although it was found that rectangular arch wires generally produced more friction than round wires, exceptions were noted. Importance of considering the occlusogingival dimension of the wires when assessing the influence of arch wire geometry was also established. For example, 0.016 inch and 0.016x0.022 inch stainless steel wires used in conjunction with 0.0185 inch slot brackets had similar frictional levels. Furthermore 0,020 inch round arch wires produced more friction at binding angulations than rectangular arch wires with smaller occlusogingival dimensions. These findings may have several rationales.

Firstly, larger wires were stiffer and the normal component of force between the wire and bracket increased with arch wire stiffness when binding occurred. Secondly, the increased pressure associated with the point contact of round wires with the bracket edge as opposed to a line contact produced with rectangular arch wires may have resulted in these findings (65). The influence of arch wire geometry and dimension on the frictional force was more pronounced at large bracket-arch wire angulations. It appears that both size and shape in conjunction with arch wire-bracket angulation are important considerations in assessing frictional resistance of orthodontic appliances.

Vaughan at al in 1995 found that when the size of the arch wire increases, the frictional force is also increasing proportionally and he stated that the rectangular wires showing higher frictional forces than round wires (115). Baker et al (1991) believed that decreased play between the bracket slot and arch wire does not allow as large a degree of wire angulation within the slot thus creating less potential for binding (6). Bednar et al (1991) tested the significance of arch wire size upon steel, ceramic and self-ligating brackets. All three types of brackets exhibited increased friction with increasing wire dimension (8).

Drescher et al. (1989) felt that the vertical dimension of the arch wire is the factor primarily responsible for friction (22). They argued that the classical physical formula defining friction, Fr = ıı x FN Their argument since FN is by definition of the force perpendicular to the plane of contact. Drescher et al found that 0.016 “ round and 0.016 x 0.022 inch rectangular stainless steel wire showed virtually the same amount of friction, if the bracket was allowed to change relative angulation. It should be pointed out that while the experimental set up by Drescher et al. (1989) did allow for three dimensional tooth rotations, the retarding force applied (simulating biologic resistance) was constant and therefore different than the dynamic process of bone remodelling seen in vitro. Frank and Nikolai (1980) also found that increasing the size of a wire resulted in increased frictional resistance at the bracket arch wire interface (28). However, they found that the effect of cross-sectional shape is depended on the bracket angulation. At non-binding (passive) angulations, rectangular wires exhibited greater frictional resistance presumably due to larger contact areas generated between the slot and arch wire compared to round wires. At binding angulations, however, stiffness and cross-sectional shape have different influences, making their effects difficult to quantify.

Round wires exhibit a point contact with the bracket, as opposed to the line

contact exhibited with a rectangular wire/bracket combination. Thus, the smaller contact area generated with round wires result in a greater force because the normal force produced will be distributed over a smaller area than with rectangular arch wires.

Conversely, they contended that because arch wire stiffness is proportional to the third or fourth power of the occluso-gingival dimension of the rectangular or round wire respectively, a smaller rectangular wire is stiffer in bending than a larger round wire of the same material. This increased stiffness will result in a greater normal force, FN, and therefore greater frictional resistance.

4.1.2.3. Surface texture

Friction between two surfaces sliding on each other is related to their surface circumstances. It is not only the surface roughness, rather geometrical shape and hardness related to each other.

Surface roughness of orthodontic arch wires has been investigated with the SEM, profilometry and specular reflectance (laser spectroscopy). Surface analysis revealed that stainless steel had the smoothest surface, followed by chromium cobalt, TMA and nickel titanium respectively. It was generally reported that friction did not always increase with an increase in surface roughness. Generally the frictional forces are higher when the surfaces are too smooth or too rough. It has been thought that very smooth surfaces are causing larger adhesion areas that are causing higher friction. For example, Kusy at al found that, although TMA demonstrated a smoother surface than nickel titanium, it had a greater coefficient of friction. Furthermore, nickel titanium wires from various manufacturers displayed tremendous variability with respect to surface roughness and smoother wires did not always produce less friction (59).

Prososki at al (1991) found no correlation between the surface roughness of arch wire and frictional forces (83). Nishio at al (1991) examined beta titanium, nickel titanium and stainless steel wires with the SEM and they found that surface roughness was highest in beta titanium and lowest in stainless steel wires (74). However they state a correlation between the surface roughness and friction levels in dry conditions.

4.1.2.4. Stiffness

Stiffness is the resistance of the wire against bending. Researches has demonstrated that friction and stiffness are inversely related due to the stronger atomic bonds within harder materials which increase the resistance to adhesion. This was confirmed with orthodontic materials. It was found that the softer titanium alloy arch wires had more friction than the harder stainless stee1 and chromium cobalt arch wire.

Kusy at al have evaluated beta titanium, stainless steel, nickel titanium and chromium cobalt wires in a position that there is such a big angle in which a binding occurs between the arch wire and the bracket. The results showed that stainless steel and chromium cobalt wires had higher friction level (65)

De Franco et al (1995) reported decreased frictional resistance with Teflon coated stainless steel ligatures compared to elastomeric ligatures (17). Question remains as to whether the Teflon coating reduces the friction compared to uncoated stainless steel ligatures because no uncoated stainless steel ligatures were used as controls in this study. The difference in frictional resistance could also be attributed to a lower force of ligation which was not quantified in the study.

4.1.3. Ligation technique of the arch wire to the bracket

In the absence of binding between the arch wire and bracket, the force of ligation was shown to have a dominant influence on the level of friction in orthodontic appliances. It was generally found that a positive linear relationship existed between the force of ligation and the friction at the bracket-arch wire interface. The significance of ligation to frictional resistance depends on the force of ligation, ligation material and method of ligation. Elastomeric modules will generate approximately 225 grams of force with subsequent decay due to elastic relaxation, while stainless steel ligation can range from 50 to 300 gram (72).

Various methods of ligation have been investigated to determine their influence on frictional resistance. One of the difficulties with investigating this effect, however, was controlling the ligation force of the various ligatures. Efforts to reduce this variability were made by using ligature pliers modified with a strain gauge which produced a digital readout. Using this method, it was found that Teflon-coated stainless steel ligatures produced the least friction, followed by conventionally tied elastomeric modules. De Franco et al (1995) reported decreased frictional resistance with Teflon coated stainless steel ligatures compared to elastomeric ligatures (17).

However question remains as to whether the Teflon coating reduces the friction compared to uncoated stainless steel ligatures because no uncoated stainless steel ligatures were used as controls in this study. The difference in frictional resistance could also be attributed to a lower force of ligation, which was also not quantified in the study.

Bednar et al (1991) found that lightly ligated stainless steel ligatures produced lower friction than conventional elastomeric ligatures (8). Similarly, Taylor and Ison (1996) found that by pre-stretching elastomeric ligatures or loosely tying stainless steel ligatures the frictional resistance would be reduced (110). Bazakidou et al (1997), on the other hand, found no significant trend for friction with either elastomeric or steel ligation (7). Yet there was up to three times greater variability in friction with stainless steel ligation than elastomeric ligation, even though it was attempted to standardize both methods of ligation.

Even between different types of elastomeric modules Dowling et al (1998) found significant differences with regard to friction (19). Sims et al (1993) demonstrated that tying elastic ligatures in a figure eight pattern around identical brackets raised the frictional resistance 70-220 percent depending on the wire dimensions (100). Larger wires led to a greater increase in friction compared to smaller wires. No significant trend in frictional resistance was observed when conventionally tied elastomeric ligatures were compared with stainless steel ligatures tightened with 7 turns.

Similarly, insignificant differences were found when stainless steel ligatures applying a force of 225 g were compared to elastomeric ligatures. The use of loosely tied stainless steel ligatures resulted in decreased friction relative to conventional elastomeric ligatures. It was demonstrated that the ligation force of elastomeric ligatures could be effectively reduced by prestreching them. Taylor and Ison (1991) also reported that the frictional force declined slowly over a three week period following initial placement of the elastic module. After three weeks, the greater friction initially encountered for rectangular wires approached the low level of friction for round wires (110).

The introduction of interactive/self-ligating brackets has also influenced the frictional force produced by orthodontic appliances. These brackets have an internal engaging precision arm which locks the arch wire into position as opposed to the conventional twin designs which employ stainless steel or elastomeric ligation. They

can be further classified as either active or passive. Active brackets are characterized by a precision arm which partially extends into the wire slot and produces a low seating force on the arch wire. Passive interactive brackets, on the other hand, have rigid precision arms which do not extend into the slot and result in minimal seating of the arch wires.

Self-ligating brackets have been reported to produce the least amount of friction but vary depending on whether the self-ligation mechanism is passive or active. However self-ligating brackets have also been toughed as applying less ligation force and hence producing less friction than conventionally ligated brackets.

4.1.4. Orthodontic appliance

4.1.4.1. Inter bracket distance

There are conflicting results as to the effect of inter bracket distance on frictional resistance. Part of the discrepancy is derived from differences in experimental protocol. Studies that do not product changes in the second order angulation of the bracket relative to the arch wire typically demonstrate that bracket width and inter bracket distance have an insignificant effect on frictional resistance compared to variables such as ligation force and arch wire or bracket surface characteristics (1). The main concern is when the angulation of the arch wire reaches the binding angle, the inter bracket distance becomes more important at the point of friction.

4.1.4.2. The point of applied force for retraction

The point of application of the retraction force on the bracket had a significant influence on frictional resistance. Studies showed that a more cervical point of application resulted in a decrease in friction. The higher friction associated with a more occlusally positioned force was a consequence of the increased binding between the bracket and arch wire secondary to the larger moments created.

4.1.4.3. Sliding velocity

Kusy and Whitley (1989) found that coefficients of friction might vary with extremes in velocity for certain arch wire alloys (58). According to the results of their study, the coefficients of frictions for the stainless steel and nickel-titanium arch

wires were relatively constant. Interestingly, the same testing conditions showed that coefficients of friction for cobalt-chromium wires increased, while those for beta-titanium wires decreased. This is contrary to the third law of friction that states that the coefficient of friction is independent of velocity. However, it has been recognized that this law is not usually followed.

Ireland et al (1991) performed a pilot study varying the cross-head speed of the Instron (37) Universal testing machine from 0.5 up to 50 mm/minute using stainless steel and nickel-titanium wires sliding in stainless steel and ceramic brackets. Results showed no significant differences in friction among the various speeds no matter what combination of brackets or arch wires was used. A speed of 5 mm/min was selected for experimentation because it was felt that higher speeds did not represent the clinical situation.

4.2. Biological Factors Influencing Friction in Orthodontic Appliances

4.2.1. Saliva

Studies investigating the effect of human saliva on fictional resistance recorded different results from those utilizing other fluid media. An earlier study found that human saliva did not influence friction. Recent studies, however, found that saliva increased the friction of stainless steel and cobalt-chromium arch wires, but decreased the friction of nickel titanium and TMA wires in conjunction with both stainless steel and ceramic brackets. TMA demonstrated the greatest reduction of up to 50 percent.

Similar results were observed with zirconia brackets coupled with TMA wires. It was suggested that saliva increased the adhesiveness of stainless steel and cobalt-chromium wires by breaking down their oxide layers (corrosion), while it provided a lubricant film for nickel titanium and TMA arch wire. Human saliva also appeared to increase the friction of elastomeric and stainless steel ligatures while it decreased the friction of Teflon-coated stainless steel ligatures. An investigation comparing the effect of various fluid media on the friction of orthodontic appliances concluded that artificial saliva resulted in much larger coefficients of friction than human saliva and therefore should not be used to stimulate the oral environment.

Andreasen and Quevedo (1970) found that saliva was not a significant factor in lubricating the surfaces of the arch wire and bracket (1). Two theories were

presented as explanation: First, they felt that saliva simply may not have the physical properties to act as a good lubricant. Second, they suggested that even if saliva was a good lubricant, it is likely excluded from areas of contact between the arch wire and bracket, thus removing any possible lubricating benefits. Ireland et al (1991) tested frictional resistance in the dry and wet states by pouring water over brackets that were moved at a fixed angulation to the arch wires (37). And he found that saliva plays an insignificant role in frictional resistance.

4.2.2. Vibration

Vibration and perturbation of the bracket wire system through the occlusal contacts during mastication, deglutition, speech and other functions can cause repeated, random, intermittent, minute relative movements at the bracket arch wire interface, significantly reducing, if not completely eliminating frictional resistance. Braun et al (1999) conducted an in vitro study in which they attempted to emulate the dynamic environment of the oral cavity by applying random perturbations in three planes of space during friction testing (11). The results showed that frictional resistance was effectively reduced with each perturbation.

A study by Iwasaki et al (2003) looked at the effects of intra oral vibration on sliding mechanics in situations with no ligation and ligation. An experimental set-up that saw stainless steel tubes, with known applied moments, sliding along an auxiliary arch wire demonstrated that intra oral vibration did decrease the apparent coefficient of static friction, however, frictional resistance was never completely eliminated as was indicated by Braun et al. (1999). When ligation forces were introduced, it was determined that intra oral vibration did not demonstrate a decrease in intra oral friction (11).

4.2.3. Corrosion

When stainless steel interacts with oxygen a passivated layer consisting of chromium oxide and chromium hydroxide is produced on the surface of the metal. This protective layer provides the corrosion resistance of stainless steel. When the integrity of this layer is undermined or broken down, metal ions from the stainless steel are released and corrosion occurs

Various types of corrosion have been implicated: crevice corrosion, pitting corrosion due to halide ions galvanic corrosion and inter granular corrosion due to excessive heating. Crevice corrosion has been the suggested mechanism for the

corrosion of orthodontic brackets. An acidic chloride environment which is reducing in nature diminishes the stability of the stainless steel oxide film and consequently facilitates corrosion. The oral cavity may therefore potentiate corrosion due to factors such as temperature, the pH of plaque, the chloride in saliva, the physical and chemical properties of nutrition and general oral health.

The corrosion of orthodontic appliances has been receiving increased awareness due to the staining of brackets, enamel and bonding resin and the escalating awareness of nickel-sensitive patients in orthodontic practices. Stainless steel orthodontic appliances contain approximately 18% chromium and 8% nickel and it has been demonstrated that these elements are released from the metal as a result of corrosion and biodegradation. One investigator noticed that some orthodontic patients presented with black and green stained bracket bases. Analysis of the discolored resin from the debonded brackets indicated that chromium, iron, nickel and chlorine were present. It was therefore concluded that the corrosion of the stainless steel brackets resulted in the leaking of chromium and nickel into the resin. These ions then formed nickel and chromium chlorides with chlorine from the saliva, and imparted their characteristic greenish-black color. Furthermore, SEM investigation of these brackets revealed some metal destruction which was suggestive of corrosion.

5. MATERIALS AND METHOD

5.1. Materials

In this study, 3 different brands of esthetic self-ligating brackets, 3 different brands of esthetic conventional brackets and 1 brand of conventional metal brackets were evaluated in terms of friction. All brands were tested in two different configurations of bracket alignment with different archwires. For each configuration of bracket alignment 10 tests were performed and totally 60 tests were done for self-ligating brackets. All of the four conventional brackets were also tested in two configurations. In each configuration, all brackets were ligated with metal ligatures, elastomeric ligatures (GAC Sani-Ties® 0.120“) and non-conventional elastomeric ligatures (Leone Slide™) and 10 tests were performed for each combination. So 240 tests were done for the conventional brackets and in total 300 tests were performed for whole study.

5.1.1. Brackets

The conventional bracket brands subjected to our study were RMO Mini-Taurus® metal, RMO signature III™ ceramic, ORMCO Inspire ICE ™ ceramic, Leone Logic line™ copolymer. The self ligating ones were Clarity™ SL (3M Unitek) Innovation™ C (GAC), and Damon® 3 (ORMCO). All brackets were in Roth prescription and had 0.018” main slots (Picture 5).

5.1.1.2. Conventional brackets

The only conventional metal bracket used in our study was Mini-Taurus® bracket of Rocky Mountain of Orthodontics (Denver, Colorado) which was selected as control. Brackets were twin brackets which were produced with the metal injection molding technique. The torque of the bracket was provided in the base of the bracket and the bonding surface was designed as a mesh.

One of the conventional esthetic brackets was Signature III™ brackets of Rocky Mountain of Orthodontics (Denver, Colorado) which was a twin bracket made of polycrystalline ceramic. The torque was provided in the base of the bracket and the bonding surface was acid etched.

The second conventional esthetic bracket was Inspire ICE bracket which was also a twin bracket made of mono crystalline structure, manufactured by Ormco

company (Glendora, Califf). Inspire ICE uses patented ball-base technology, which reduces the required force to debond.

The third conventional esthetic bracket was Logic line™ bracket of Leone company (Florence, Italy). The structure of bracket is micro-filled copolymer and the bonding surface has a special design which was called as micro-cell by Leone.

5.1.1.3. Self ligating brackets

Clarity™ SL bracket is a self ligating bracket produced by 3M Unitek. The structure is micro crystalline and produced with ceramic injection molding technique. The bonding surface has a special design to create mechanical locking. It has an open slot with 3 SSl walls and has nickel titanium metal clips on the sides to hold the wire inside the slots.

Innovation™ C bracket is the self-ligating esthetic bracket of GAC. It is a ceramic self-ligating bracket with interactive chromium-cobalt clip. The interactive clip is rhodium coated and it becomes active after a level of arch dimension.

Damon® 3 bracket is manufactured by Ormco company (Glendora Califf). It is made of stainless steel and composite. Since the slot and the clip of the bracket is made of stainless steel it is not as esthetic compared to other esthetic self-ligating brackets. The clip has a passive design and has a special instrument to open it.

5.1.2. Arch wires

In our study, preformed (standard) nickel titanium 0.014" RMO archwires were used in the tests for the crowded configuration of the bracket alignment. For the aligned configuration of the brackets 0.016" RMO straight stainless steel wires were used.

5.1.3. Ligating materials and methods

Three different ligation methods have been used in order to ligate the conventional brackets. They were metal ligatures, elastomeric ligatures and non-conventional elastomeric ligatures.

Metal ligatures used in the study were 0.010" stainless steel, elastomeric ligatures were Sani-Ties® 0.120 "of GAC company and non-conventional elastomeric

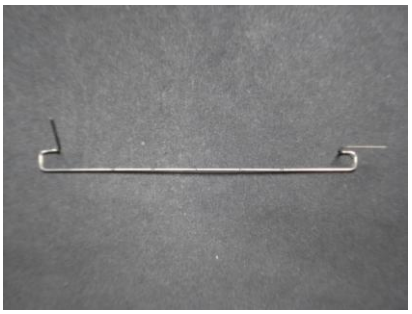
ligatures were Slide™ low friction elastomeric ligatures of Leone company (Picture 3, 4).

5.1.4. The special designed jig and light cure adhesive

For the correct and repeatable bracket placement on the metal plates a special designed jig has been prepared for each configuration. These special designed jigs were bended of 0.017”x0.025” stainless steel wire to ensure that the brackets have no angulations and no torque while fixing on the metal plates. The points that the brackets are going to be fixed were marked with aerator on the jigs (Picture 1, 2).

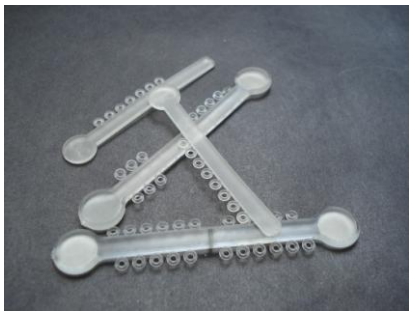
In order to fix the brackets on the metal plates Transbond XT 3M Unitek light cure bracket adhesive and bonding materials were used.

Picture 1 Jig for the crowded configuration



Picture 2. Jig for the aligned configuration

Picture 3. Leone Slide ligatures



Picture 4, Elastomeric lig. (GAC)

Picture 5. Brackets tested in our study

5.2. Method

In our study, we aimed to measure the frictional forces of different brands and types of the brackets. Two different test configurations have been prepared. The first one was designed to mimic the starting phase of the treatment and 0.014" nickel titanium archwires were used for testing. The second configuration was designed to mimic the frictional forces of brackets after the leveling phase of the treatment by and straight 0.016" stainless steel wires were used for testing.

5.2.1. Preparing the metal plates

To be able to perform the tests 90 mm in length, 70 mm in width and 2 mm of thickness stainless steel plates has been prepared. Two different bracket configurations were designed for the study. One of them was prepared to mimic the initial (usually crowded) phase of treatment so the canine brackets were positioned 2 mm superior and 2 mm buccal in relation to the anterior and posterior brackets. In order to raise the canine bracket, an extra 2 mm thick and 6 mm width metal plate was glued along the canine area over the standard plate (picture 8, 9, 14). In the second design the brackets were placed on the same line using the special jig (Picture 10).

Firstly, 30 metal plates have been produced with a hole 3mm in diameter in the right lower corner of the plates for screwing to the testing machine. The points where the brackets are going to be placed on the plates were marked and sand blasted in order to increase the bonding strength. Than all surfaces were cleaned by using alcohol. Inter bracket distance has been determined as 8,5 mm and the points that the brackets are going to be placed were marked on the jigs,. As it was mentioned before jigs were designed as to zero the torque and angulation values which were provided in the bracket base. Each bracket was ligated to the jigs either with metal ligatures or by closing their lids.

While fixing the brackets on the metal plates, first the bonding agent was applied and light cured for 10 seconds and than the light cure adhesive was applied

on bracket bases and light cured 20 seconds with the led. After light curing, the jigs were removed and the metal plates were ready for testing.

5.2.2. The transferring apparatus

Following bonding of the brackets, stainless steel plates were screwed to a special designed transfer apparatus which has specially prepared screw holes on it.

This apparatus is fixed to the lower jaw of the testing machine and keeps the stainless steel plate perpendicular to the archwires which are fixed to the upper jaw of the testing machine (Picture 8, 9).

5.2.3. Preparing the test samples

For the aligned configuration, 150 piece of 20 cm long straight 0.016" stainless steel wires and for the crowded configuration 150 pieces of 0.014" nickel titanium preformed arch wires were prepared and used.

The tests were performed for;

1-Three different self ligating brackets (Clarity SL, Damon 3, Innovation C)

2-Three different conventional esthetic brackets and one metal bracket (Signature III, Inspire ICE, Logic Line, Mini Taurus) ligated with metal ligatures,

3-Three different conventional esthetic brackets and one metal bracket (Signature III, Inspire ICE, Logic Line, Mini Taurus) ligated with elastomeric ligatures,

4-Three different conventional esthetic brackets and one metal bracket (Signature III, Inspire ICE, Logic Line, Mini Taurus) ligated with slide ligatures.

While ligating with the elastomeric ligatures, a ligature gun was used in order to have better standardization. While ligating with metal ligatures, 7 turns were performed for each standard ligature and squeezed at the sides as Bazakidou did in his study in 1998.

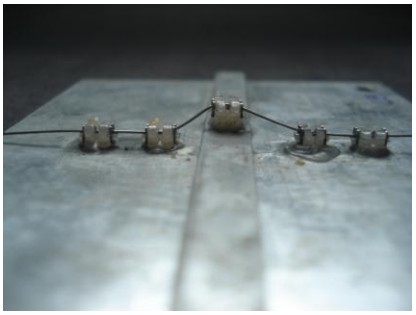
15 test groups were formed for each configuration (aligned and crowded) which makes a total of 30 test groups. For each group the tests were repeated 10 times. Before each test, the wire was removed, the testing machine was recalibrated and a new wire was inserted for the new test.

5.2.4. Test procedures and measuring the frictional forces

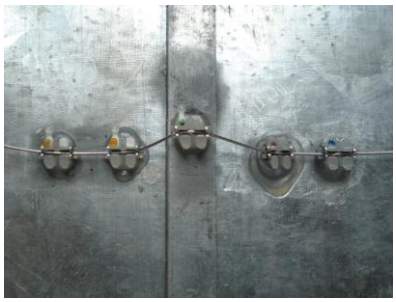
All tests were carried on in Tubitak-UME scientific research center in Gebze, Izmit. The Zwick-Roell Z250 testing machine was used to perform the friction tests (picture 11). This machine has two jaws located upper and lower. The lower jaw is steady and the upper jaw is mobile. The stress revealed during tests was measured and monitored on the screen connected to the system. All the data were recorded in Test-Expert soft ware program.

First, the metal plates with brackets and the wires on, were fixed to the transferring part of the testing machine with a screw and a clamp and the transferring apparatus was fixed to the lower jaw of the machine. Following that, upper end of the test wire is fixed to the upper jaw of the machine and a 200gr weight was attached to the lower end of the wire in order to standardize the wire tension.(picture 8)

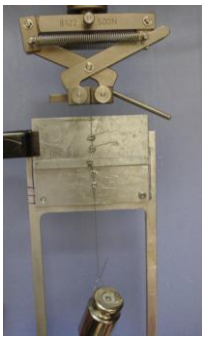
The pulling speed was set to 10 mm/min and the test continued 30 seconds for each sample. With the help of stress sensor in the upper jaw of the machine frictional forces were measured for 30 seconds. The recording was started after revealing residual stresses at the testing wires. The static frictional as well as kinetic frictional force values at the 5th, 10th and 15th seconds were recorded by the software. For each sample, all bracket-ligation combinations were tested 10 times. So we recorded 4 values for each test and totally 40 values for each bracket/ligation method combination. Before each test, the wire was removed, the testing machine was recalibrated and a new wire was inserted for the new test.



Picture 6 (crowded configuration)



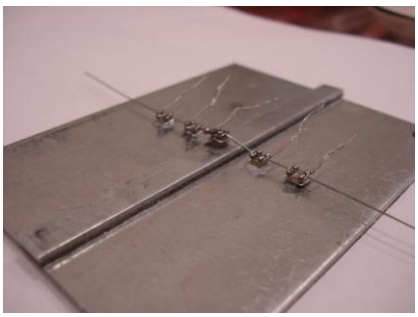
Picture 7 (crowded configuration)



Picture 8 Picture 9

Picture 10 (aligned configuration)

Picture 11 (testing unit)



Picture 12 (crowded configuration)

5.2.5. Statistical Analyses

NCSS 2007 & PASS 2008 Statistical Software (Utah, USA) program has been used in the evaluation of the results. Oneway Anova test was used in comparison of Quantitative data and in intergroup comparisons, followed by Tukey HDS as post hoc test. Student t test was used in double group comparisons. The results were evaluated at $p<0.05$ significance level with a confidence interval of 95%.

Statistical analyses, which were made for both aligned and crowded configurations, were mainly as follows.

1- Comparison of frictional values of different ligation methods free of bracket brands

2- Comparison of the frictional values of conventional brackets ligated with different methods

3- Comparison of the frictional values of self ligating brackets

4- Comparison of the frictional values of the self ligating brackets and conventional brackets ligated with GAC elastomeric and metal ligatures

5- Comparison of the frictional values of the self ligating brackets and nonconventionally (Leone Slide ligatures) ligated conventional brackets

6. RESULTS

The results will be evaluated in two configurations:

A: Crowded Configuration

B: Aligned Configuration.

6.1. Crowded Configuration

Crowded configuration of bracket alignment was mimicking the initial phase of treatment and the tests were performed with 0,014" preformed nickel titanium archwires.

6.1.1. Evaluation of frictional forces of the bracket brands according to the ligation methods at the crowded configuration

Table 2. Evaluation of frictional forces of the bracket brands according to the ligation methods (crowded configuration)(*F:Oneway ANOVA test ** p<0.01)*

Ligation method	**Bracket brand**	**Force-F (N)**	***p***
		mean±SD	
GAC Elastomeric Ligature	**Leone logic Line**	**7,42±0,13**	***F:527,325 p:0,001****
	Inspire ICE	**15,12±0,29**	
	RMO Mini Taurus	**12,15±0,63**	
	RMO Signature lll	**13,07±0,55**	
Slide Ligature	**Leone logic Line**	**4,33±0,07**	***F:502,925 p:0,001****
	Inspire ICE	**8,23±0,28**	
	RMO Mini Taurus	**6,54±0,22**	
	RMO Signature lll	**6,26±0,25**	
Metal Ligature	**Leone logic Line**	**7,37±0,19**	***F:836,345 p:0,001****
	Inspire ICE	**15,37±0,48**	
	RMO Mini Taurus	**12,59±0,48**	
	RMO Signature lll	**14,62±0,35**	
Self Ligating Brackets	**Clarity SL**	**7,51±0,30**	***F:426,844 p:0,001****
	Damon 3	**7,47±0,30**	
	Innovation C	**12,29±0,59**	

Table 3. Evaluation of frictional forces of bracket brands with different ligation methods in couple comparison by using Tukey test (crowded configuration)

Bracket brand	GAC Elastic Ligature	Slide Ligature	Metal Ligature
	p	p	p
Leone logic Line Inspire ICE	*0,001***	*0,001***	*0,001***
Leone Logic Line RMO Mini Taurus	*0,001***	*0,001***	*0,001***
Leone Logic Line RMO Signature lll	*0,001***	*0,001***	*0,001***
Inspire ICE RMO Mini Taurus	*0,001***	*0,001***	*0,001***
Inspire ICE RMO Signature lll	*0,001***	*0,001***	*0,001***
RMO Mini Taurus RMO Signature lll	*0,001***	*0,048**	*0,001***

Tukey test * $p<0.05$ ** $p<0.01$

Frictional values of conventional brackets ligated with all three ligation methods (GAC ligatures, Slide Ligatures and metal ligatures) showed significant results.

6.1.1.1. GAC elastomeric ligature method

The mean frictional values of Inspire ICE brackets ligated with GAC elastomeric ligatures were significantly higher than those of all other samples ($p<0.01$). The mean frictional values of Leone Logic Line brackets were significantly lower than those of all other samples ($p<0.01$). The mean frictional values of RMO Signature lll brackets were significantly higher than those of the RMO Mini Taurus brackets ($p<0.01$) (Table 2, 3, Fig. 1).

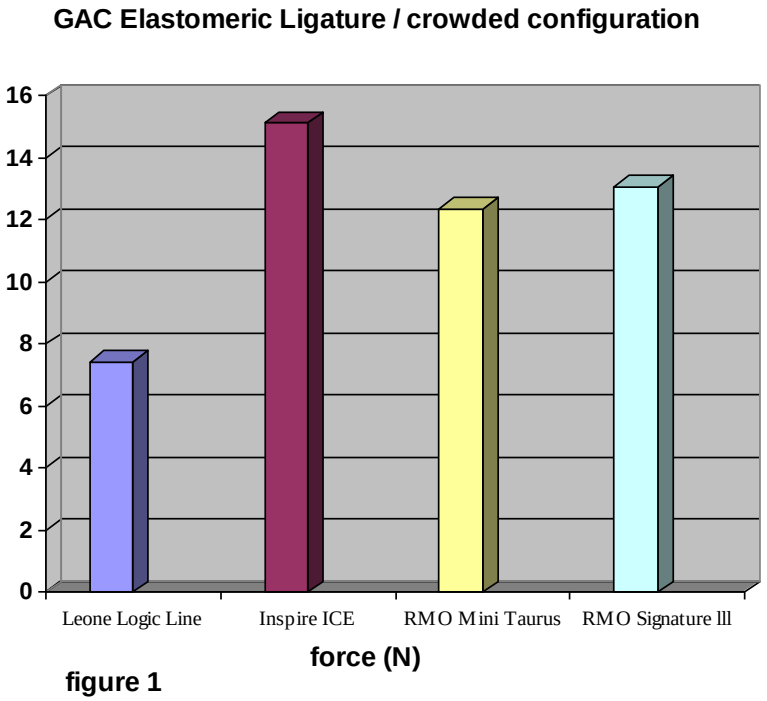


figure 1

6.1.1.2. Leone Slide ligature method

The mean frictional values of Leone Logic Line brackets ligated with Slide ligatures were significantly lower than those of all other samples ($p<0.01$). The mean frictional values of Inspire ICE brackets were significantly higher than those of all other samples ($p<0.01$). The mean frictional values of RMO Signature lll brackets were significantly lower than those of the RMO Mini Taurus brackets ($p<0.05$) (Table 2, 3, Fig. 2).

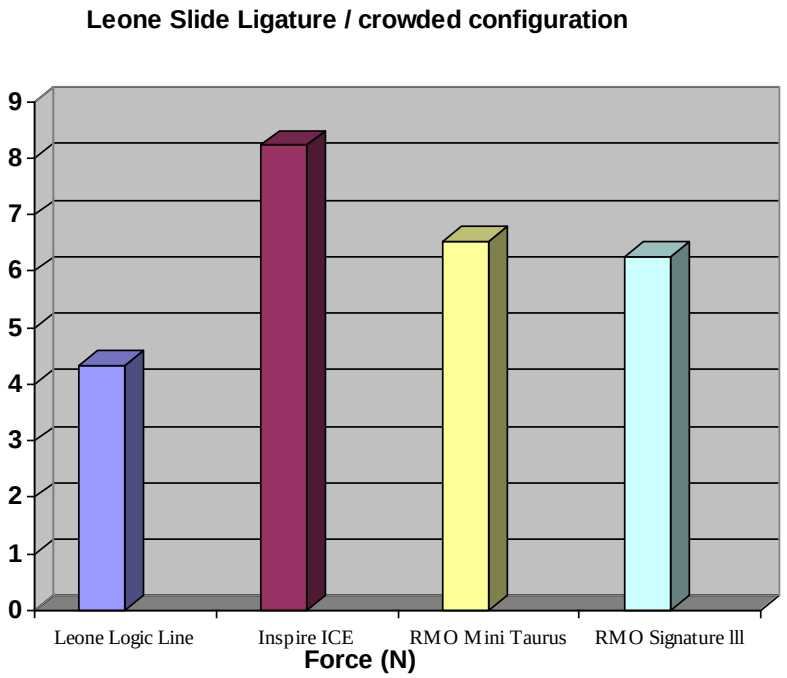


figure 2

6.1.1.3. Metal ligature method

The mean frictional values of Inspire ICE brackets ligated with metal ligatures were significantly higher than those of all other samples ($p<0.01$). The mean frictional values of Leone Logic Line brackets were significantly lower than those of all other samples ($p<0.01$). The mean frictional values of RMO Signature lll brackets were significantly higher than those of the RMO Mini Taurus brackets ($p<0.01$) (Table 2, 3, Fig. 3).

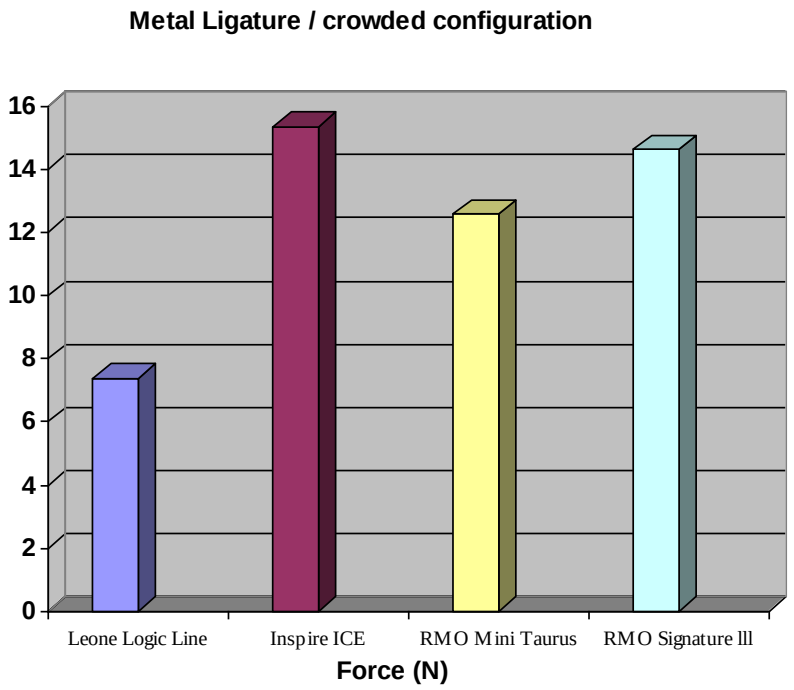


figure 3

6.1.1.4. Self ligating brackets

Table 4. Evaluation of frictional forces of self ligating brackets in couple comparison (crowded configuration)

Ligation Method	Tukey
	p
Innovation C- Clarity SL	*0,001***
Clarity SL - Damon 3	*0,969*
Damon 3- Innovation C	*0,001***

Tukey test *** p<0.01*

There were statistically significant difference among the self ligating esthetic brackets (p<0.01). The mean frictional values of Innovation C brackets were significantly higher than those of the Clarity SL (p<0.01) and Damon 3 (p<0.01) brackets.There was no significant difference between the mean frictional values of Clarity SL and Damon 3 brackets (p>0.05) (Table 2, 4, Fig. 4).

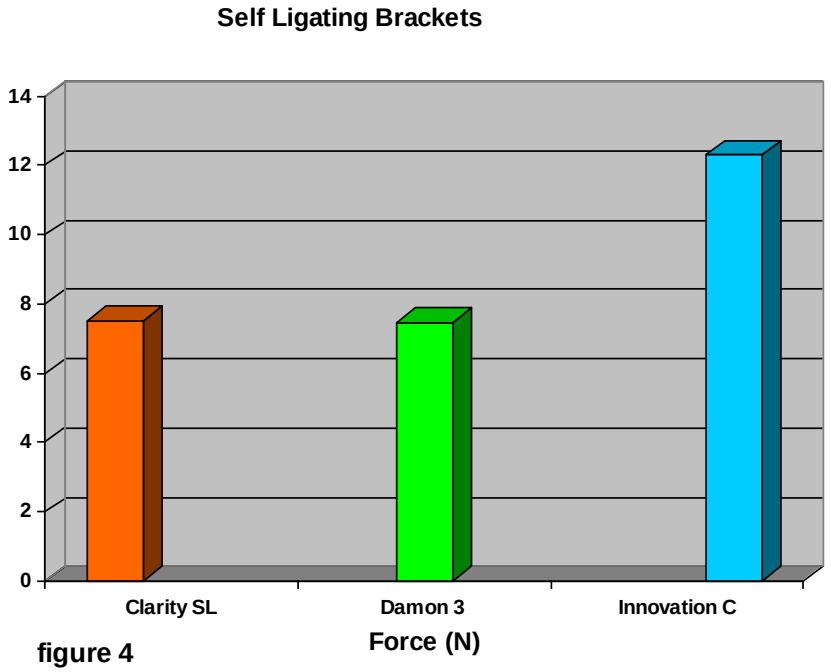


figure 4

6.1.2. Evaluation of mean frictional forces of three different ligation methods free of bracket brands at the crowded configuration

In the second step of evaluation, all frictional values of conventional brackets related to ligation methods (free from the bracket brands) were collected together and compared.

Table 5. Evaluation of mean frictional forces of three different ligation methods (crowded configuration)

Ligation Method	Force-F (N)	*p*
	Mean±SD	
GAC Elastic Ligature	11,94±2,89	*F:67,702* *p:0,001***
Slide Ligature	6,34±1,41	
Metal Ligature	12,49±3,18	

F:Oneway ANOVA test *** p<0.01*

Table 6. Evaluation of frictional forces of ligation methods in couple comparison (crowded configuration)

Ligation Method	Tukey
	p
GAC Elastic Ligature Slide Ligature	*0,001***
GAC Elastic Ligature Metal Ligature	*0,616*
Slide Ligature Metal Ligature	*0,001***

Tukey test *** p<0.01*

The mean frictional values of Leone Slide ligating method were significantly lower than those of the GAC elastic ligating and metal ligating ($p<0.01$). There was statistically no significant difference between the GAC elastic ligation method and metal ligature ligation method ($p>0.05$) (Table 5, 6, Fig. 5).

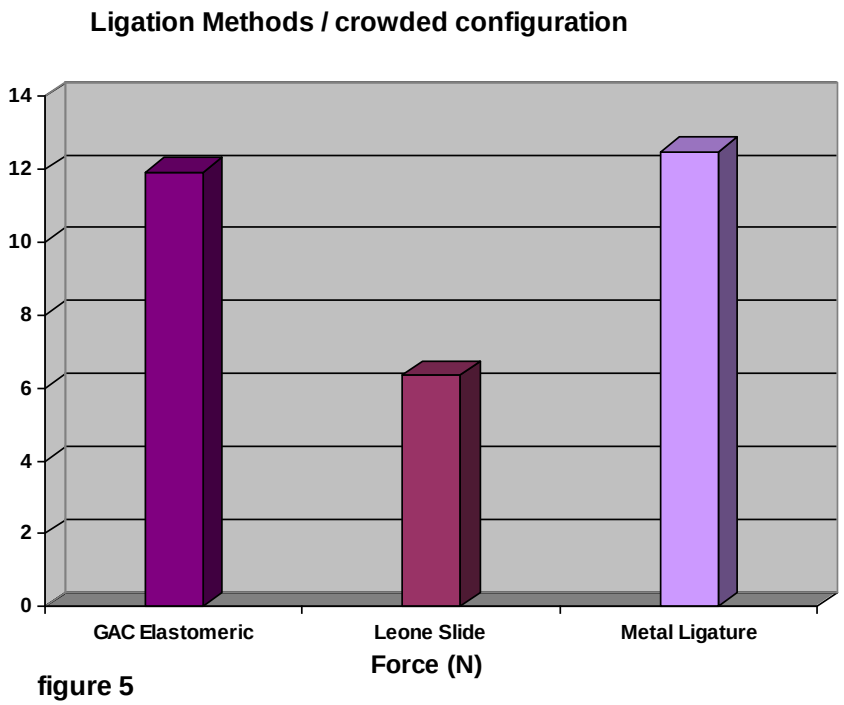


figure 5

6.1.3. Evaluation of the mean frictional values of ligation methods in accordance with bracket brands at the crowded configuration

Table 7. Evaluation of the mean frictional values of ligation methods in accordance with bracket brands. (crowded configuration)

Bracket Brand	Ligation Method	Force-F (N) Mean±SD	*p*
Leone Logic Line	GAC Elastic Ligature	7,42±0,13	*F:1602,027 p:0,001***
	Slide Ligature	4,33±0,07	
	Metal Ligature	7,37±0,19	
Inspire Ice	GAC Elastic Ligature	15,12±0,29	*F:1234,617 p:0,001***
	Slide Ligature	8,23±0,28	
	Metal Ligature	15,37±0,48	
RMO Mini Taurus	GAC Elastic Ligature	12,15±0,63	*F:501,543 p:0,001***
	Slide Ligature	6,54±0,22	
	Metal Ligature	12,59±0,48	
RMO Signature lll	GAC Elastic Ligature	13,07±0,55	*F:1206,135 p:0,001***
	Slide Ligature	6,26±0,25	
	Metal Ligature	14,62±0,35	

F:Oneway ANOVA test *** p<0.01*

Table 8.Evaluation of frictional forces of ligation methods in couple comparison by using Tukey test on different bracket brands.

	Leone Logic	Inspire ICE	RMO Mini Taurus	RMO Signature lll
GAC Elastik Ligature Slide Ligature	*0,001***	*0,001***	*0,001***	*0,001***
GAC Elastik Ligature Metal Ligature	*0,727*	*0,281*	*0,116*	*0,001***
Slide Ligature Metal Ligature	*0,001***	*0,001***	*0,001***	*0,001***

6.1.3.1. Leone Logic Line

The mean frictional values of Leone Logic Line brackets ligated with Leone slide ligatures were significantly lower than those of the GAC elastomeric ligatures and metal ligatures ($p<0.01$). There was statistically no significant difference between the frictional values of Leone Logic Line brackets when ligated with GAC elastic ligature or metal ligature ($p>0.05$) (Table7, 8, Fig. 6).

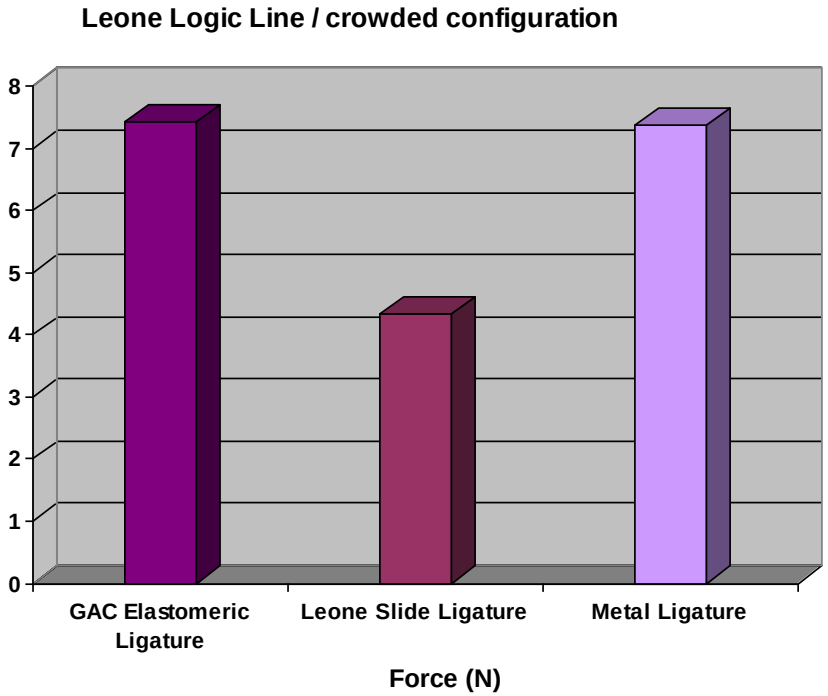


figure 6

6.1.3.2. Inspire ICE

The mean frictional values of Leone Slide ligating method were significantly lower than those of the GAC elastic ligatures and metal ligatures ($p<0.01$).There was statistically significant difference between the GAC elastic ligature and metal ligature method ($p>0.05$) (Table 7, 8, Fig. 7).

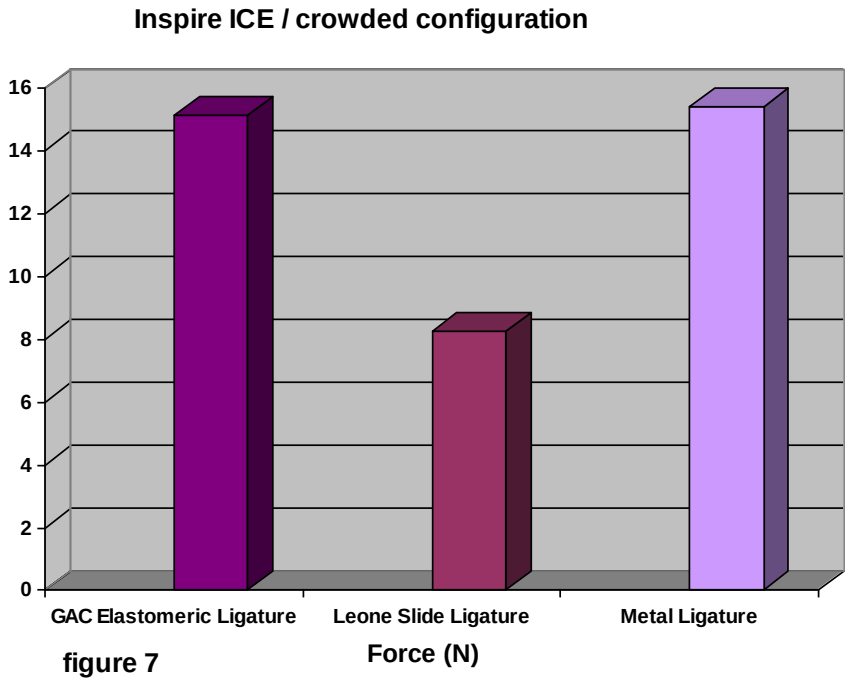


figure 7

6.1.3.3. RMO Mini Taurus

The mean frictional values of Leone slide ligating method were significantly lower than those of the GAC elastic ligatures and metal ligatures ($p<0.01$).There was statistically significant difference between the GAC elastic ligation method and metal ligature ligation method ($p>0.05$) (table7, 8, Fig. 8)

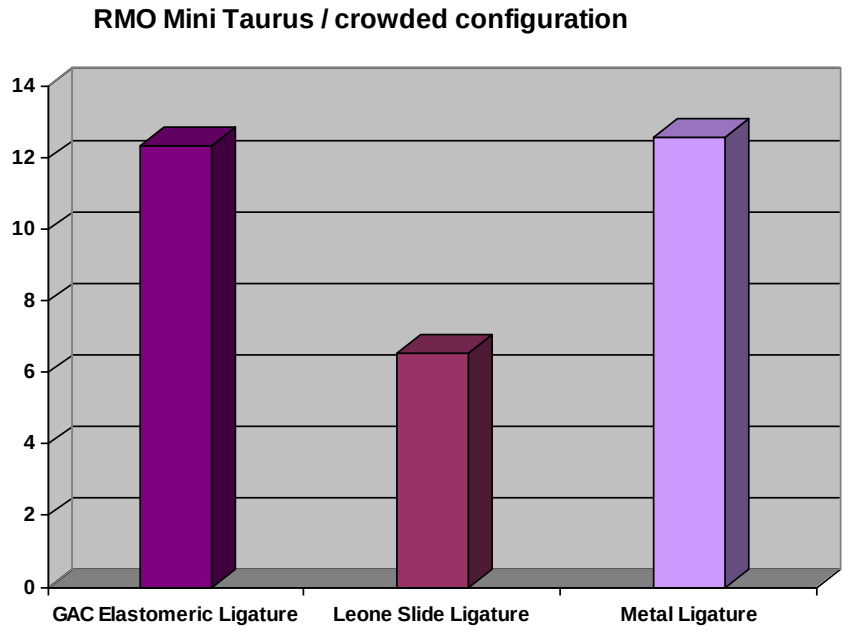


figure 8

6.1.3.4. RMO Signature lll

The mean frictional values of Leone slide ligating method were significantly lower than those of the GAC elastic ligatures and metal ligatures ($p<0.01$). The mean frictional values of Metal Ligatures ligating method were significantly higher than those of the GAC elastic ligation method ($p<0.01$) (Table 7, 8, Fig. 9).

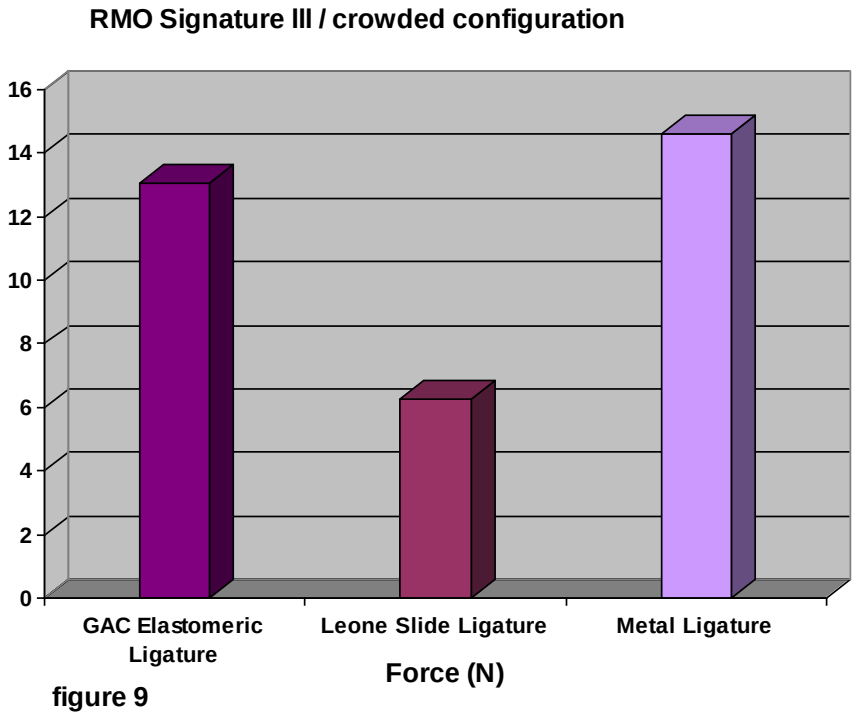


figure 9

6.1.4. Evaluation of frictional values of self ligating brackets and conventional brackets ligated with different ligation methods at the crowded configuration

Table 9.Comparison of frictional values of self ligating / Conventional brackets ligated with GAC elastic ligatures

Bracket / GAC elastics	Force-F (N) mean±SD	*p*
Clarity SL	**7,51±0,30**	***t:0,470***
Leone Logic Line / GAC Elastic Ligature	**7,42±0,13**	***p:0,647***
Clarity SL	**7,51±0,30**	***t:57,468***
Inspire Ice/GAC Elastic Ligature	**15,12±0,29**	***p:0,001*****
Clarity SL	**7,51±0,30**	***t:21,137***
RMO Mini Taurus/ GAC Elastic Ligature	**12,15±0,63**	***p:0,001*****
Clarity SL	**7,51±0,30**	***t:28,260***
RMO Signature lll/ GAC Elastic Ligature	**13,07±0,55**	***p:0,001*****
Damon 3M	**7,47±0,30**	***t:0,903***
Leone Logic Line / GAC Elastic Ligature	**7,42±0,13**	***p:0,384***
Damon 3M	**7,47±0,30**	***t:57,023***
Inspire Ice / GAC Elastic Ligature	**15,12±0,29**	***p:0,001*****
Damon 3M	**7,47±0,30**	***t:20,919***
RMO Mini Taurus / GAC Elastic Ligature	**12,15±0,63**	***p:0,001*****
Damon 3M	**7,47±0,30**	***t:28,008***
RMO Signature lll / GAC Elastic Ligature	**13,07±0,55**	***p:0,001*****
Innovation C	**12,29±0,59**	***t:25,164***
Leone Logic Line / GAC Elastic Ligature	**7,42±0,13**	***p:0,001*****
Innovation C	**12,29±0,59**	***t:13,414***
Inspire Ice / GAC Elastic Ligature	**15,12±0,29**	***p:0,001*****
Innovation C	**12,29±0,59**	***t:0,510***
RMO Mini Taurus / GAC Elastic Ligature	**12,15±0,63**	***p:0,616***
Innovation C	**12,29±0,59**	***t:3,024***
RMO Signature lll / GAC Elastic Ligature	**13,07±0,55**	***p:0,007*****

t:Student t test *** p<0.01*

6.1.4.1 Self-ligating brackets and conventional brackets ligated with GAC elastomeric ligatures

6.1.4.1.A.Clarity SL / Conventional brackets ligated with GAC elastic ligatures

The difference between the mean frictional values of Clarity SL brackets and Leone Logic Line brackets ligated with GAC elastic ligatures were statisticaly insignificant. ($p>0.05$). The mean frictional values of Clarity SL brackets were significantly lower than those of Inspire ICE brackets, RMO Mini Taurus brackets and RMO Signature lll brackets ligated with GAC elastic ligatures ($p<0.01$) (Table 9, Fig. 10).

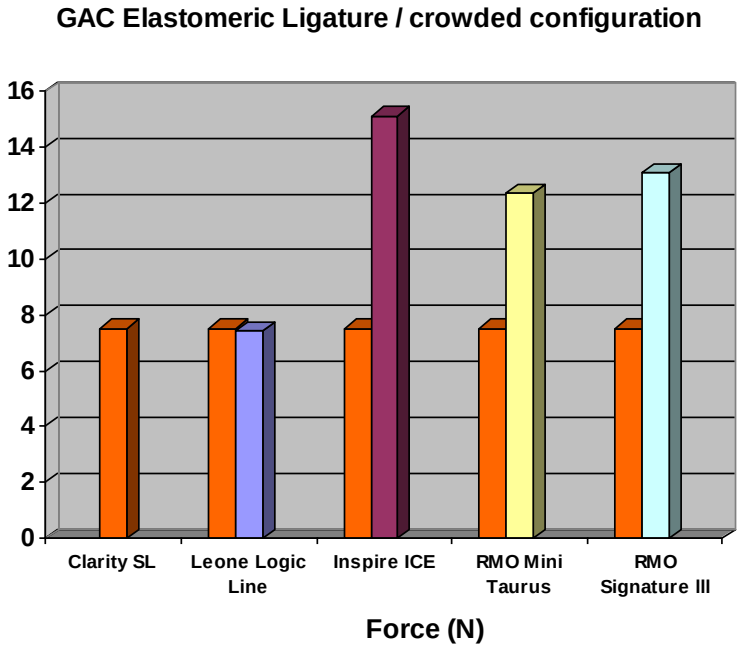


figure 10

6.1.4.1. B Damon 3 / Conventional brackets ligated with GAC elastomeric ligatures

The difference between the mean frictional values of Damon 3 brackets and Leone Logic Line brackets ligated with GAC elastic ligatures were statisticaly insignificant. ($p>0.05$). The mean frictional values of Damon 3 brackets were significantly lower than those of Inspire ICE brackets, RMO Mini Taurus brackets and RMO Signature lll brackets ligated with GC elastic ligatures ($p<0.01$) (Table 9, Fig. 11).

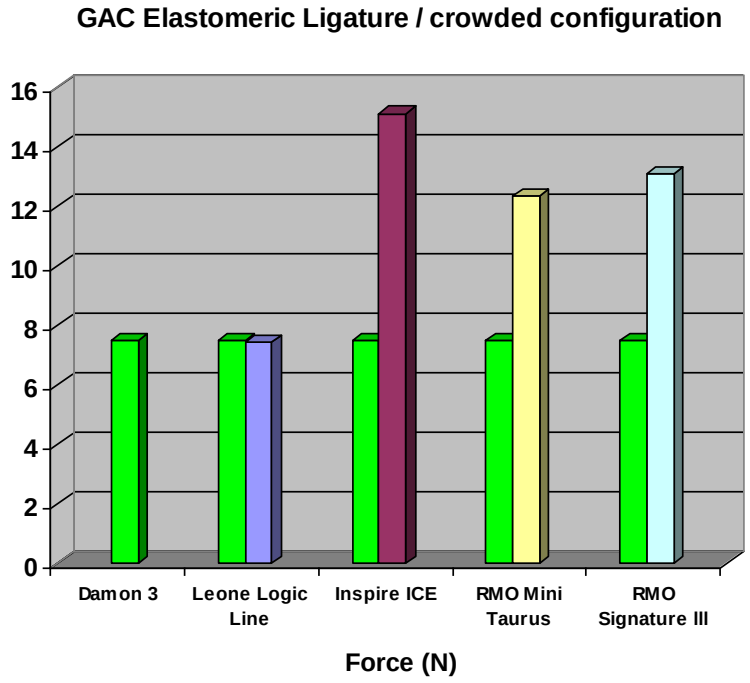


figure 11

6.1.4.1.C. Innovation C / Conventional brackets ligated with GAC elastomeric ligatures

The difference between the mean frictional values of Innovation C brackets and RMO Mini Taurus brackets ligated with GAC elastic ligatures were statisticaly insignificant. ($p>0.05$).The mean frictional values of Innovation C brackets were significantly lower than those of Inspire ICE brackets and RMO Signature lll brackets ligated with GAC elastic ligatures ($p<0.01$). The mean frictional values of Innovation C brackets were significantly higher than those of Leone Logic Line brackets ligated with GAC elastic ligatures ($p<0.01$) (Table 9, Fig. 12).

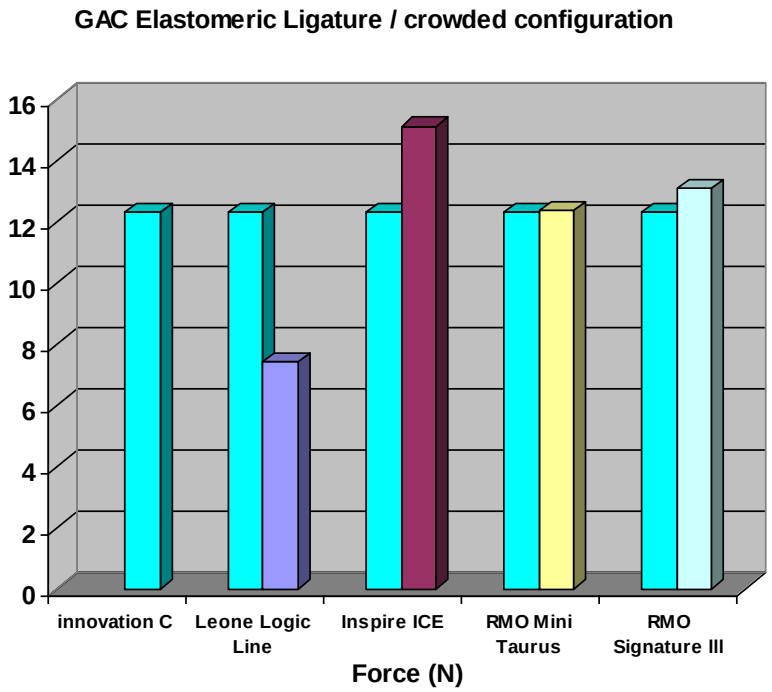


figure 12

Table 10. Comparison of frictional values of self ligating brackets and conventional brackets ligated with Leone Slide ligatures (crowded configuration)

Bracket / Slide ligature	**Force-F (N)**	***p***
	Mean±SD	
Clarity SL	7,51±0,30	***t:31,954***
Leone Logic Line / Leone Slide ligatures	4,33±0,07	***p:0,001*****
Clarity SL	7,51±0,30	***t:5,780***
Inspire Ice/ Leone Slide ligatures	8,23±0,28	***p:0,001*****
Clarity SL	7,51±0,30	***t:7,812***
RMO Mini Taurus/ Leone Slide ligatures	6,54±0,22	***p:0,001*****
Clarity SL	7,51±0,30	***t:9,689***
RMO Signature lll/ Leone Slide ligatures	6,26±0,25	***p:0,001*****
Damon 3M	7,47±0,30	***t:32,303***
Leone Logic Line / Leone Slide ligatures	4,33±0,07	***p:0,001*****
Damon 3M	7,47±0,30	***t:5,426***
Inspire Ice / Leone Slide ligatures	8,23±0,28	***p:0,001*****
Damon 3M	7,47±0,30	***t:8,172***
RMO Mini Taurus / Leone Slide ligatures	6,54±0,22	***p:0,001*****
Damon 3M	7,47±0,30	***t:10,031***
RMO Signature lll / Leone Slide ligatures	6,26±0,25	***p:0,001*****
Innovation C	12,29±0,59	***t:41,713***
Leone Logic Line / Leone Slide ligatures	4,33±0,07	***p:0,001*****
Innovation C	12,29±0,59	***t:19,388***
Inspire Ice / Leone Slide ligatures	8,23±0,28	***p:0,001*****
Innovation C	12,29±0,59	***t:28,428***
RMO Mini Taurus / Leone Slide ligatures	6,54±0,22	***p:0,001*****
Innovation C	12,29±0,59	***t:29,336***
RMO Signature lll / Leone Slide ligatures	6,26±0,25	***p:0,001*****

t:Student t test *** p<0.01*

6.1.4.2. Self ligating brackets and conventional brackets ligated with Leone Slide ligatures

6.1.4.2.A. Clarity SL / Conventional brackets ligated with Leone Slide ligatures

The mean frictional values of Clarity SL brackets were significantly lower than those of Inspire ICE brackets ligated with Leone Slide ligatures ($p<0.01$). The mean frictional values of Clarity SL brackets were significantly higher than those of RMO Mini Taurus brackets, Leone Logic Line brackets and RMO Signature lll brackets ligated with Leone Slide ligatures ($p<0.01$) (Table 10, Fig. 13).

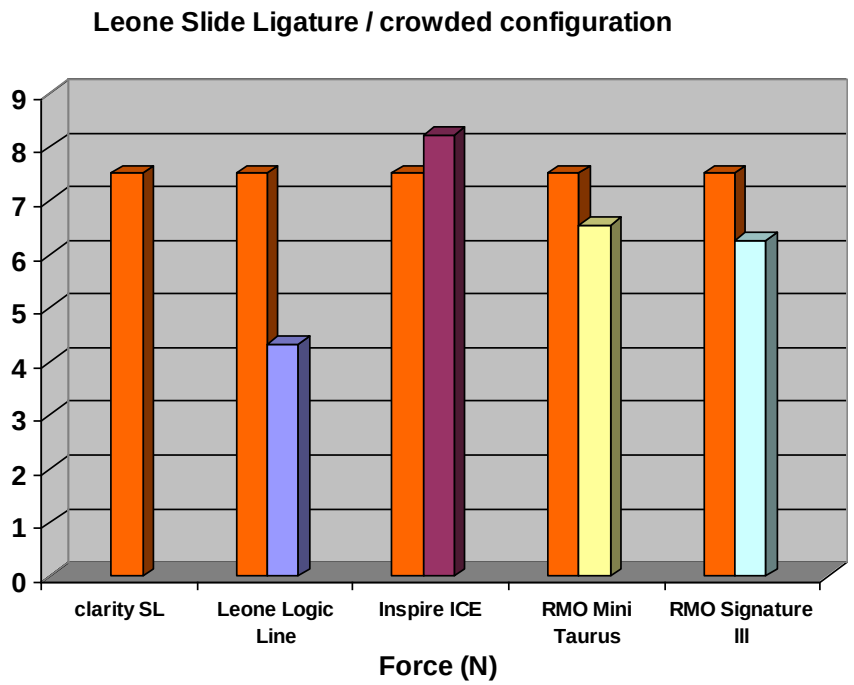


figure 13

6.1.4.2.B. Damon 3 / Conventional brackets ligated with Leone Slide ligatures

The mean frictional values of Damon 3 brackets were significantly lower than those of Inspire ICE brackets ligated with Leone Slide ligatures ($p<0.01$).The mean frictional values of Damon 3brackets were significantly higher than those of Leone Logic Line brackets, RMO Mini Taurus brackets and RMO Signature lll brackets ligated with Leone Slide ligatures ($p<0.01$) (Table 10, Fig. 14).

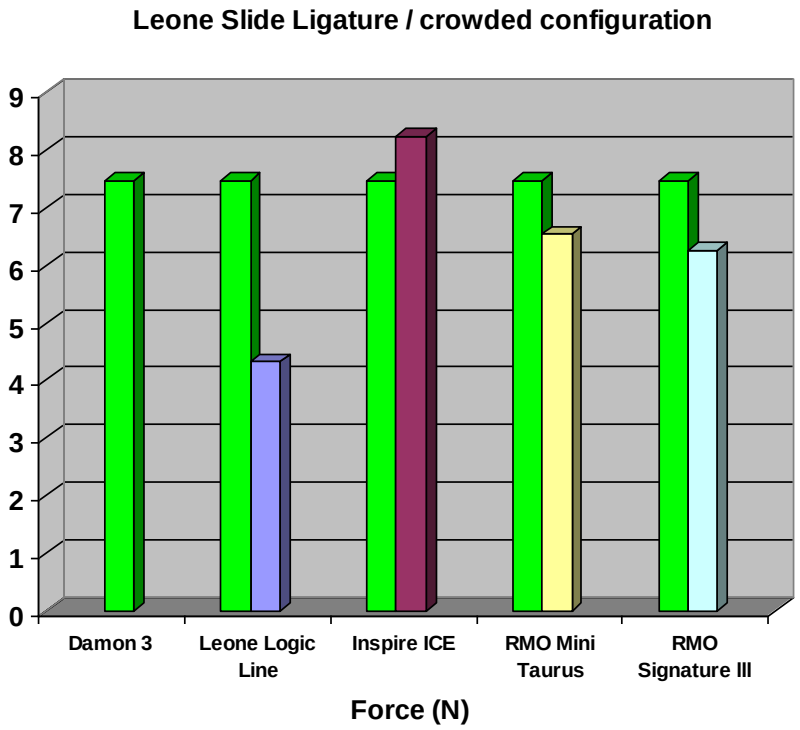


figure 14

6.1.4.2.C. Innovation C / Conventional brackets ligated with Leone Slide ligatures

The mean frictional values of Innovation C brackets were significantly higher than those of Leone Logic Line brackets, Inspire ICE brackets, RMO Mini Taurus brackets and RMO Signature lll brackets ligated with Leone Slide ligatures ($p<0.01$) (Table 10, Fig. 15).

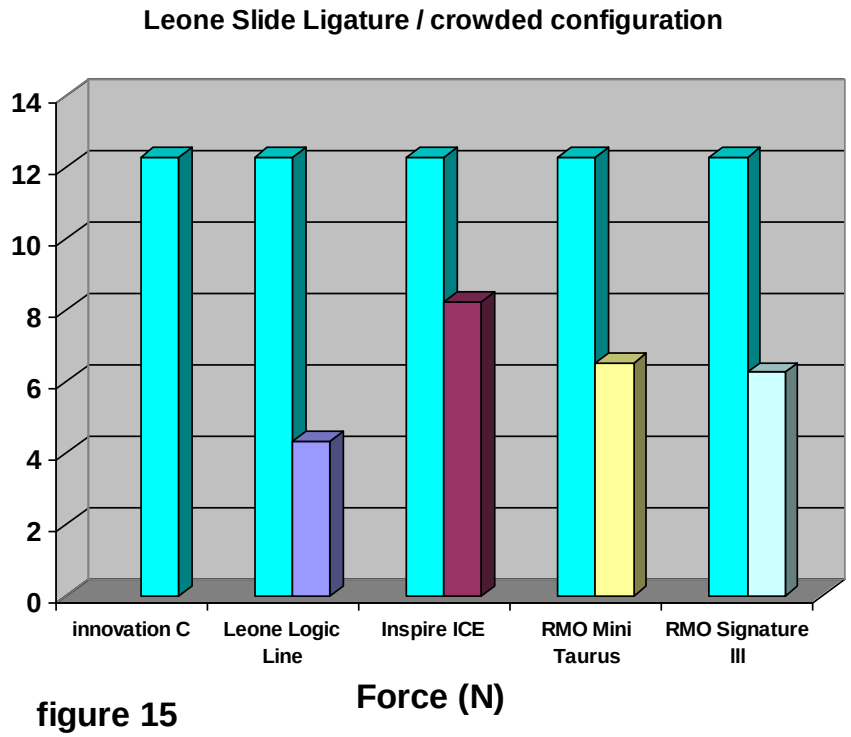


figure 15

Table 11. Comparison of frictional values of self ligating brackets and conventional brackets ligated with metal ligatures

Bracket / Metal ligature	Force-F (N) Ort±SD	*p*
Clarity SL	7,51±0,30	***t:0,856***
Leone Logic Line / Metal ligatures	7,37±0,19	***p:0,403***
Clarity SL	7,51±0,30	***t:44,059***
Inspire Ice/ Metal ligatures	15,37±0,49	***p:0,001*****
Clarity SL	7,51±0,30	***t:28,628***
RMO Mini Taurus/ Metal ligatures	12,59±0,48	***p:0,001*****
Clarity SL	7,51±0,30	***t:48,682***
RMO Signature lll/ Metal ligatures	14,62±0,35	***p:0,001*****
Damon 3	7,47±0,30	***t:1,254***
Leone Logic Line / Metal ligatures	7,37±0,19	***p:0,226***
Damon 3	7,47±0,30	***t:43,763***
Inspire Ice / Metal ligatures	15,37±0,49	***p:0,001*****
Damon 3	7,47±0,30	***t:28,347***
RMO Mini Taurus / Metal ligatures	12,59±0,48	***p:0,001*****
Damon 3	7,47±0,30	***t:48,301***
RMO Signature lll / Metal ligatures	14,62±0,35	***p:0,001*****
Innovation C	12,29±0,59	***t:24,769***
Leone Logic Line / Metal ligatures	7,37±0,19	***p:0,001*****
Innovation C	12,29±0,59	***t:12,699***
Inspire Ice / Metal ligatures	15,37±0,49	***p:0,001*****
Innovation C	12,29±0,59	***t:1,237***
RMO Mini Taurus / Metal ligatures	12,59±0,48	***p:0,232***
Innovation C	12,29±0,59	***t:10,594***
RMO Signature lll / Metal ligatures	14,62±0,35	***p:0,001*****

t:Student t test *** p<0.01*

6.1.4.3. Self ligating brackets and conventional brackets ligated with metal ligatures

6.1.4.3.A. Clarity SL / conventional brackets ligated with metal ligatures

The difference between the mean frictional values of Clarity SL brackets and Leone Logic Line brackets ligated with metal ligatures were statisticaly insignificant. ($p>0.05$). The mean frictional values of Clarity SL brackets were significantly lower than those of Inspire ICE brackets, RMO Mini Taurus brackets and RMO Signature lll brackets ligated with metal ligatures ($p<0.01$) (Table 11, Fig. 16) .

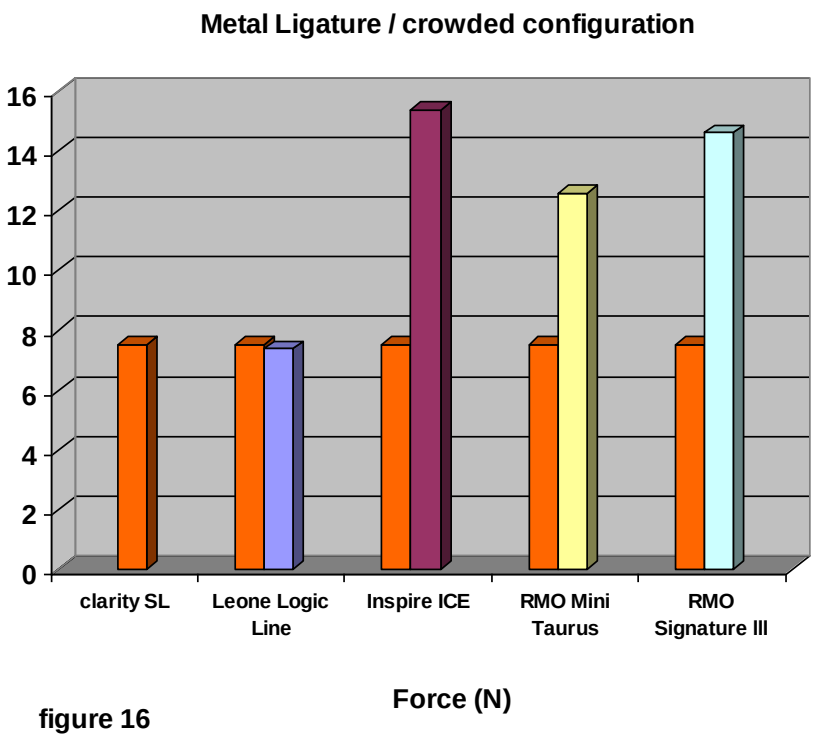


figure 16

6.1.4.3.B. Damon 3 / conventional brackets ligated with metal ligatures

The difference between the mean frictional values of Damon 3 brackets and Leone Logic Line brackets ligated with metal ligatures were statisticaly insignificant. ($p>0.05$). The mean frictional values of Damon 3 brackets were significantly lower than those of Inspire ICE brackets, RMO Signature lll brackets and RMO Mini Taurus brackets ligated with metal ligatures ($p<0.01$) (Table 11, Fig. 17).

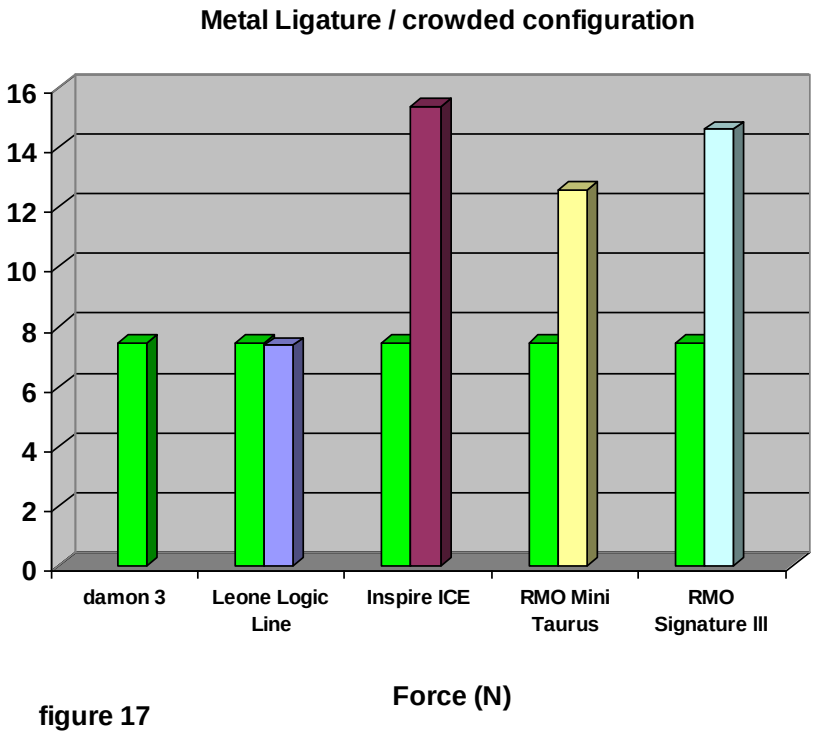


figure 17

6.1.4.3.C. Innovation C / conventional brackets ligated with metal ligatures

The mean frictional values of Innovation C brackets were significantly higher than those of Leone Logic Line brackets ligated with metal ligatures ($p<0.01$). The mean frictional values of Innovation C brackets were significantly lower than those of Inspire ICE brackets and RMO Signature lll brackets ligated with Leone Slide ligatures ($p<0.01$). The difference between the mean frictional values of Innovation C brackets and RMO Mini Taurus brackets were statistically insignificant ($p>0.05$) (Table 11, Fig. 18).

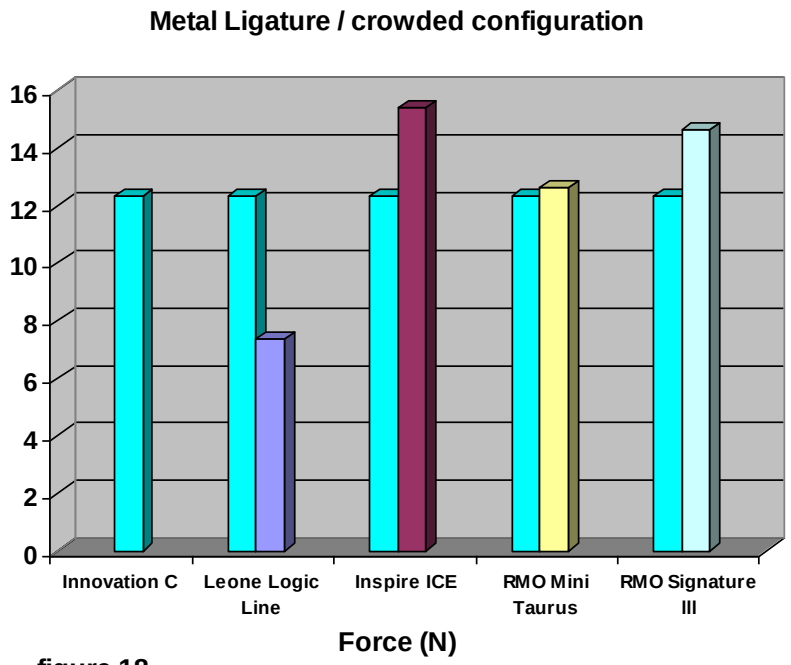


figure 18

6.2. Aligned Configuration

Aligned configuration of the bracket alignment was mimicking the leveled phase of the treatment and the tests were performed with 0.016" stainless steel arch wires.

6.2.1. Evaluation of frictional forces of the bracket brands according to the ligation methods at the aligned configuration

Table 12.Evaluation of frictional forces of the bracket brands according to the ligation methods (aligned configuration)

Ligation method	Bracket brand	Force-F (N) mean±SD	p
GAC Elastic Ligature	Leone logic Line	7,30±0,13	*F:124,381 p:0,001***
	Inspire ICE	8,28±0,25	
	RMO Mini Taurus	6,94±0,18	
	RMO Signature lll	7,05±0,08	
Slide Ligature	Leone logic Line	2,07±0,03	*F:145,518 p:0,001***
	Inspire ICE	2,13±0,02	
	RMO Mini Taurus	1,99±0,01	
	RMO Signature lll	2,02±0,01	
Metal Ligature	Leone logic Line	2,49±0,04	*F:444,841 p:0,001***
	Inspire ICE	2,10±0,02	
	RMO Mini Taurus	2,19±0,02	
	RMO Signature lll	2,30±0,02	
Self Ligating Brackets	Clarity SL	2,17±0,01	*F:815,549 p:0,001***
	Damon 3	1,99±0,00	
	Innovation C	2,13±0,02	

Table 13. Evaluation of frictional forces of bracket brands in couple comparison with different ligation methods by using Tukey tests (aligned configuration)

Bracket brand	GAC Elastic Ligature	Slide Ligature	Metal Ligature
	p	p	p
Leone logic Line Inspire ICE	*0,001***	*0,001***	*0,001***
Leone Logic Line RMO Mini Taurus	*0,001***	*0,001***	*0,001***
Leone Logic Line RMO Signature lll	*0,012**	*0,001***	*0,001***
Inspire ICE RMO Mini Taurus	*0,001***	*0,001***	*0,001***
Inspire ICE RMO Signature lll	*0,001***	*0,001***	*0,001***
RMO Mini Taurus RMO Signature lll	*0,52*	*0,001***	*0,001***

Tukey test *** p<0.05** ****p<0.01**

Frictional values of conventional brackets ligated with all three ligation methods (GAC ligatures, Slide Ligatures and metal ligatures) showed significant results.

6.2.1.1. GAC elastomeric ligature method

The mean frictional values of Inspire Ice brackets were significantly high compared to all other samples ($p<0.01$). The mean frictional values of Leone logic Line brackets were significantly high compared to Mini Taurus ($p<0.01$) and Signature lll brackets ($p<0.05$). There was statistically no significant difference between the mean frictional values of Mini Taurus and Signature lll brackets ($p>0.05$) (Table 12, 13, Fig. 19).

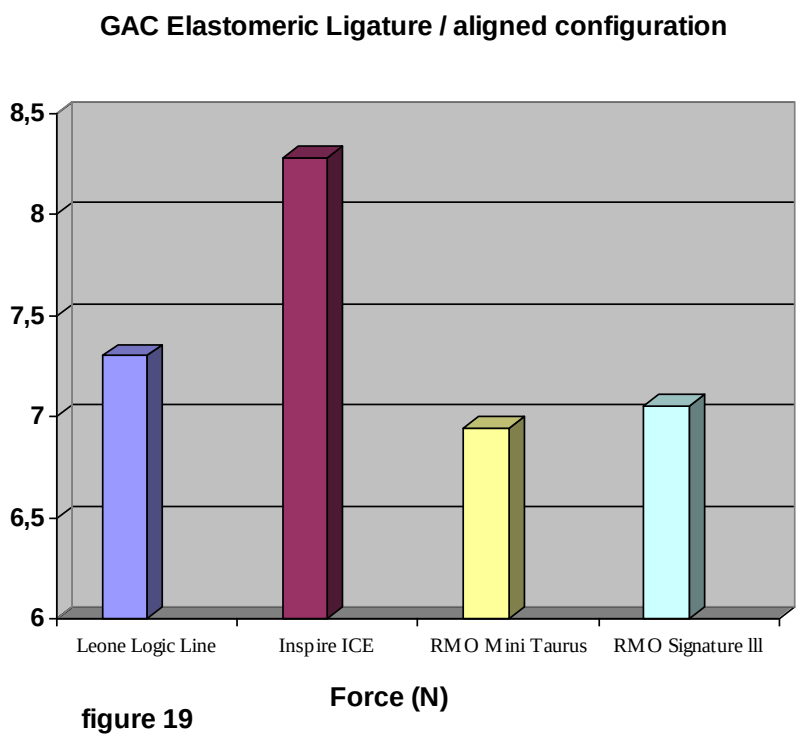


figure 19

6.2.1.2. Leone Slide ligature method

The mean frictional values of Inspire Ice brackets were significantly high compared to all other samples (p:<0.01). The mean frictional values of Leone logic Line brackets were significantly high compared to Mini Taurus and Signature lll brackets (p:<0.01). The mean frictional values of Signature lll brackets were significantly higher than Mini Taurus brackets (p:<0.01) (Table 12, 13, Fig .20)

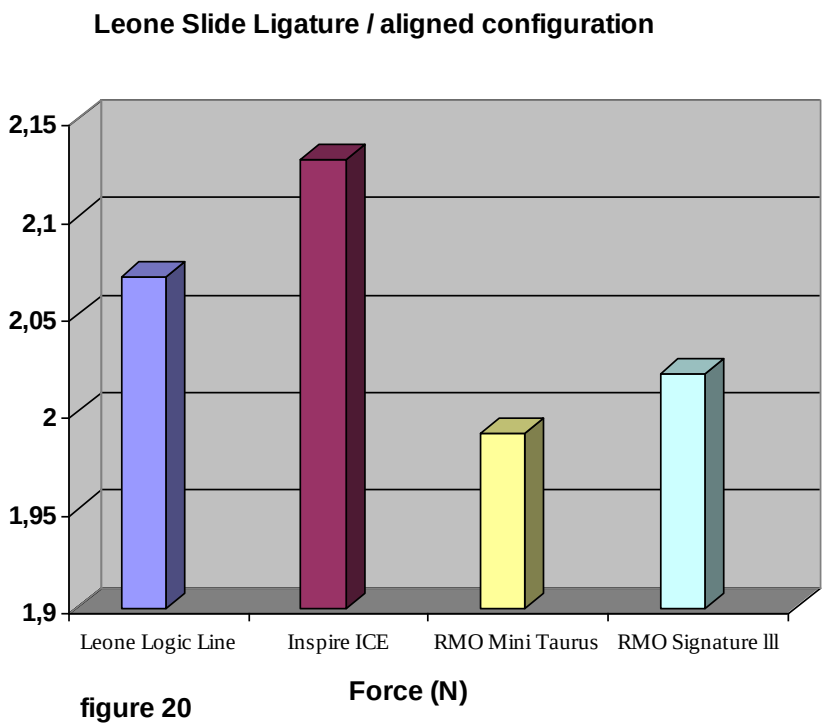


figure 20

6.2.1.3. Metal ligature method

The mean frictional values of Leone Slide brackets were significantly high compared to all other samples ($p<0.01$). The mean frictional values of Signature lll brackets were high compared to Mini Taurus and Inspire Ice brackets ($p<0.01$). The mean frictional values of Mini Taurus brackets were significantly higher than that of the Inspire Ice brackets ($p<0.01$) (Table 12, 13, Fig. 21).

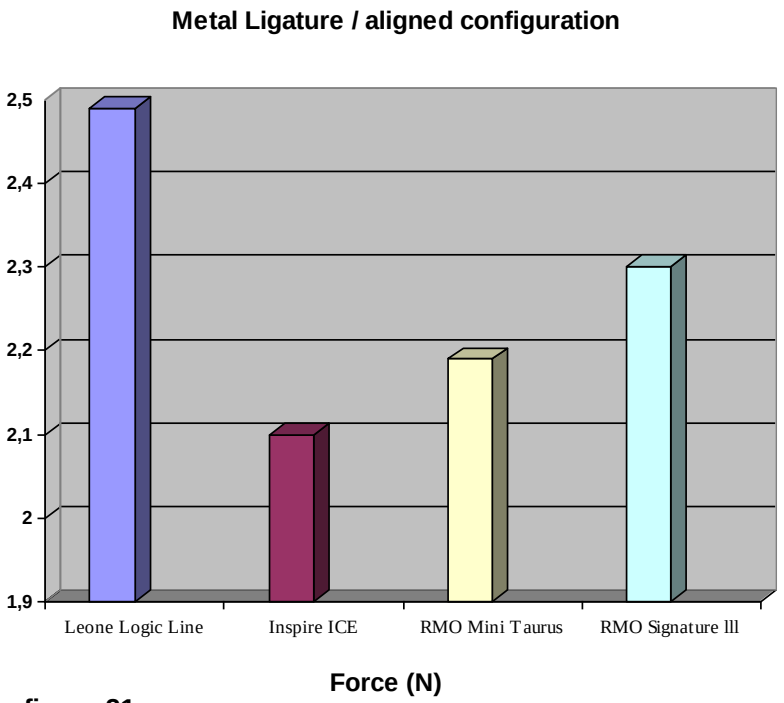


figure 21

6.2.1.4. Self ligating brackets

Table 14. Evaluation of frictional forces of self ligating brackets in couple comparison (aligned configuration)

Ligation Method	Tukey
	p
Innovation C- Clarity SL	*0,001***
Clarity SL - Damon 3	*0,001***
Damon 3- Innovation C	*0,001***

Tukey test *** p<0.01*

There were statistically significant difference among the self ligating esthetic brackets (p<0.01). The mean frictional values of Clarity SL brackets were significantly higher than that of the Innovation C and Damon 3 brackets (p<0.01). The mean frictional values of innovation C brackets were significantly higher than that of the Damon 3 brackets (Table 14, Fig 22).

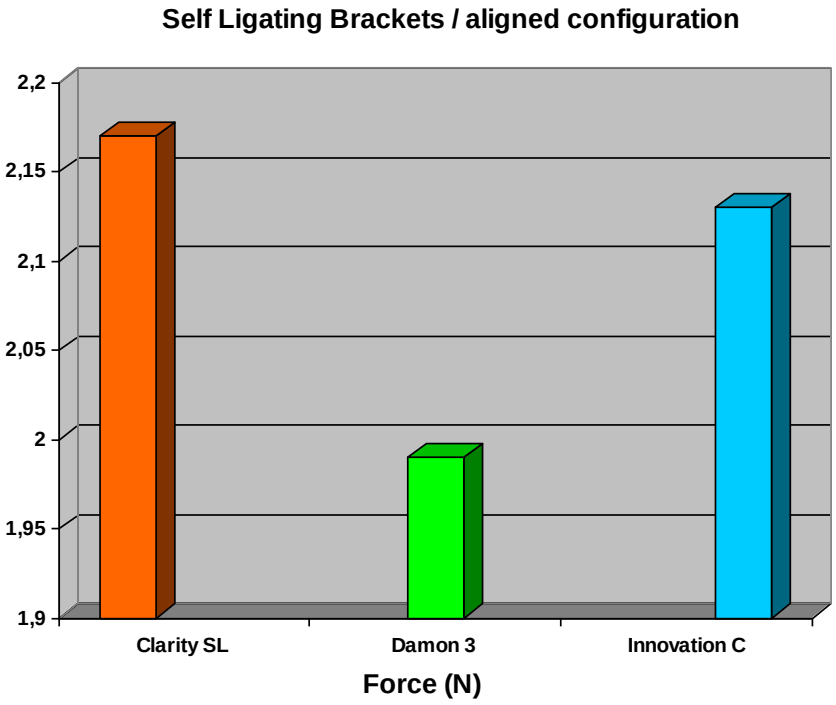


figure 22

6.2.2. Evaluation of mean frictional forces of three different ligation methods free of bracket brands at the aligned configuration

In the second step of evaluation, all frictional values of conventional brackets related to ligation methods (free from the bracket brands) were collected together and compared.

Table 15. Evaluation of the mean frictional forces of different ligation methods (aligned configuration)

Ligation Method	**Force-F (N)**	***p***
	mean±SD	
GAC Elastic Ligature	**7,39±0,56**	***F:3204,402***

Slide Ligature	**2,05±0,06**	***p:0,001***
Metal Ligature	**2,27±0,15**	

F:Oneway ANOVA test ***** p<0.01***

Table 16. Evaluation of frictional forces of ligation methods in couple comparison (aligned configuration)

Ligation Method	**Tukey**
	p
GAC Elastic Ligature **Slide Ligature**	***0,001****
GAC Elastic Ligature **Metal Ligature**	***0,001****
Slide Ligature **Metal Ligature**	***0,015****

Tukey test ***** p<0.05*** ***** p<0.01***

The mean frictional values of GAC elastic ligature were significantly higher than that of the Slide ligatures and metal ligatures (p<0.01). The mean frictional value of slide ligature were significantly lower than that of the metal ligature (p<0.05) (Table 15, 16, Fig. 23).

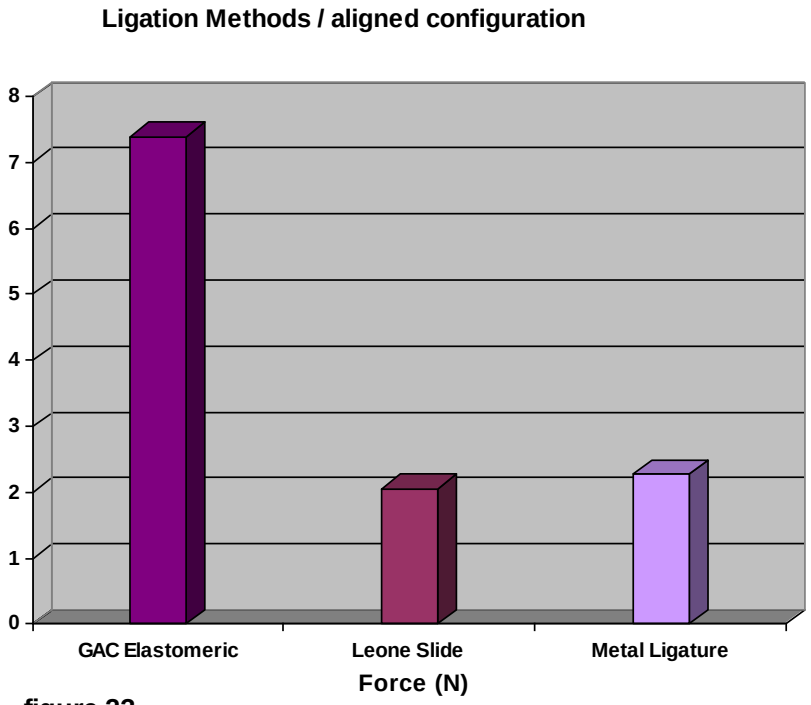

Ligation Methods / aligned configuration
8
7
6
5
4
3
2
1
0
GAC Elastomeric
Leone Slide
Metal Ligature
Force (N)

figure 23

6.2.3. Evaluation of the mean frictional values of ligation methods in accordance with the bracket brands at the aligned configuration

Table 17. Evaluation of the mean frictional values of ligation methods in accordance with the bracket brands (aligned configuration)

Bracket Brand	Ligation Method	Force-F (N) Mean±SD	*p*
Leone Logic Line	GAC Elastic Ligature	7,30±0,13	*F:13568,044 p:0,001***
	Slide Ligature	2,07±0,03	
	Metal Ligature	2,49±0,04	
Inspire Ice	GAC Elastic Ligature	8,28±0,25	*F:5818,463 p:0,001***
	Slide Ligature	2,13±0,02	
	Metal Ligature	2,10±0,02	
RMO Mini Taurus	GAC Elastic Ligature	6,94±0,18	*F:6982,468 p:0,001***
	Slide Ligature	1,99±0,01	
	Metal Ligature	2,19±0,02	
RMO Signature lll	GAC Elastic Ligature	7,05±0,08	*F:37084,547 p:0,001***
	Slide Ligature	2,02±0,01	
	Metal Ligature	2,30±0,02	

F:Oneway ANOVA test *** p<0.01*

Table 18.Evaluation of frictional forces of ligation methods in couple comparison by using Tukey test on different bracket brands

	Leone Logic Line	Inspire ICE	RMO Mini Taurus	RMO Signature lll
	p	p	p	p
GAC Elastic Ligature Slide Ligature	*0,001***	*0,001***	*0,001***	*0,001***
GAC Elastic Ligature Metal Ligature	*0,001***	*0,001***	*0,001***	*0,001***
Slide Ligature Metal Ligature	*0,001***	*0,86*	*0,001***	*0,001***

Tukey test *** p<0.01*

6.2.3.1 Leone Logic Line

The mean frictional value of GAC ligation method was significantly higher than those of the Slide ligatures and Metal ligatures (p<0.01). The mean frictional value of Slide ligation method was significantly lower than that of the metal ligation method. (p<0.01) (Table 17, 18, Fig. 24)

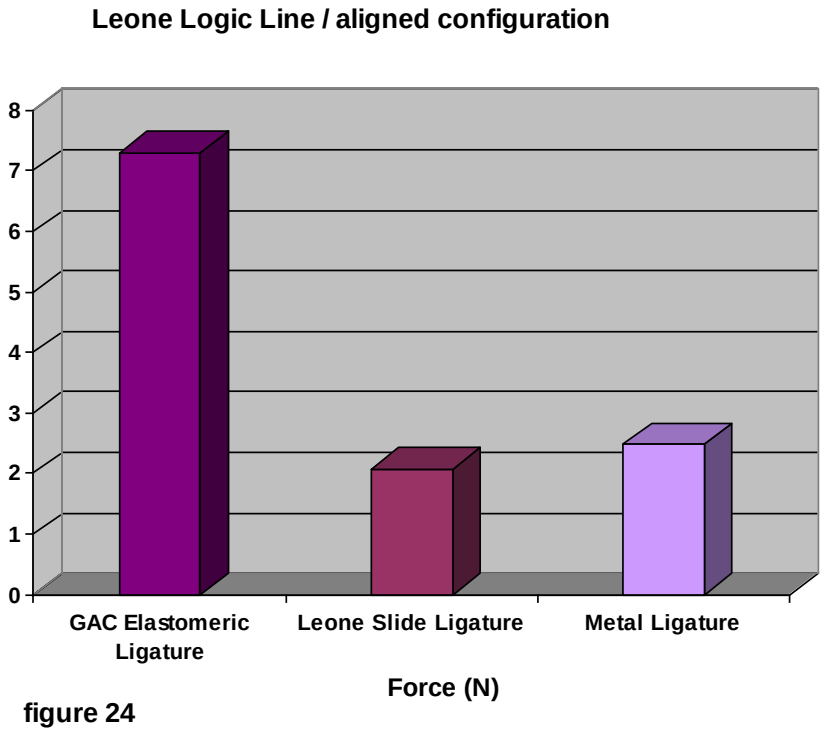


figure 24

6.2.3.2. Inspire ICE

The mean frictional value of GAC ligation method was significantly higher than those of the Slide ligatures and Metal ligatures ($p<0.01$). There was no statistically significant difference between the Slide ligation and Metal ligation methods at inspire Ice brackets ($p>0.05$) (Table 17, 18, Fig. 25)

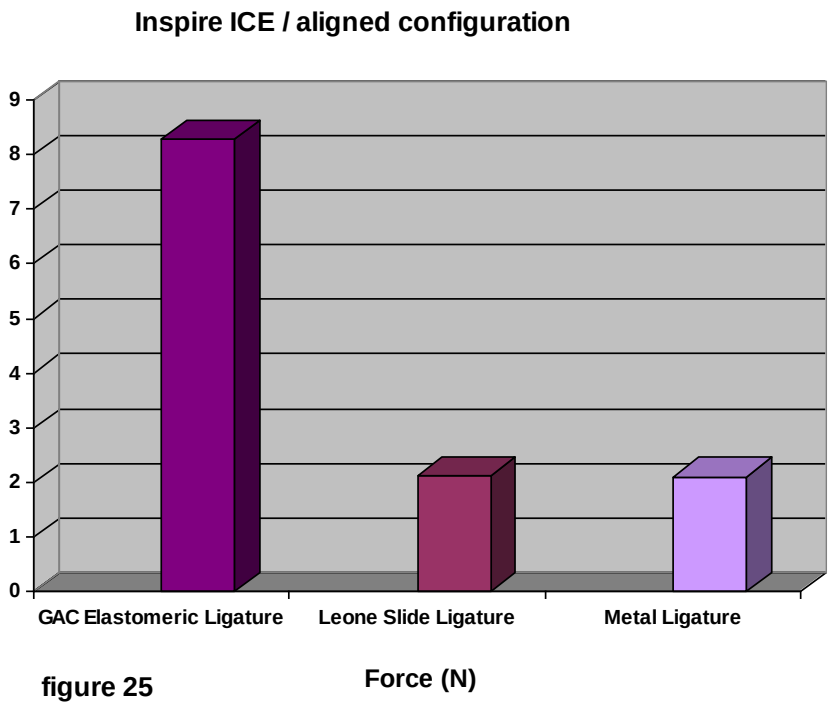


figure 25

6.2.3.3. RMO Mini Taurus

The mean frictional value of GAC ligation method was significantly higher than those of the Slide ligatures and Metal ligatures ($p<0.01$). The mean frictional value of Slide ligation method was significantly lower than that of the metal ligation method. ($p<0.01$) (Table 17, 18, Fig. 26)

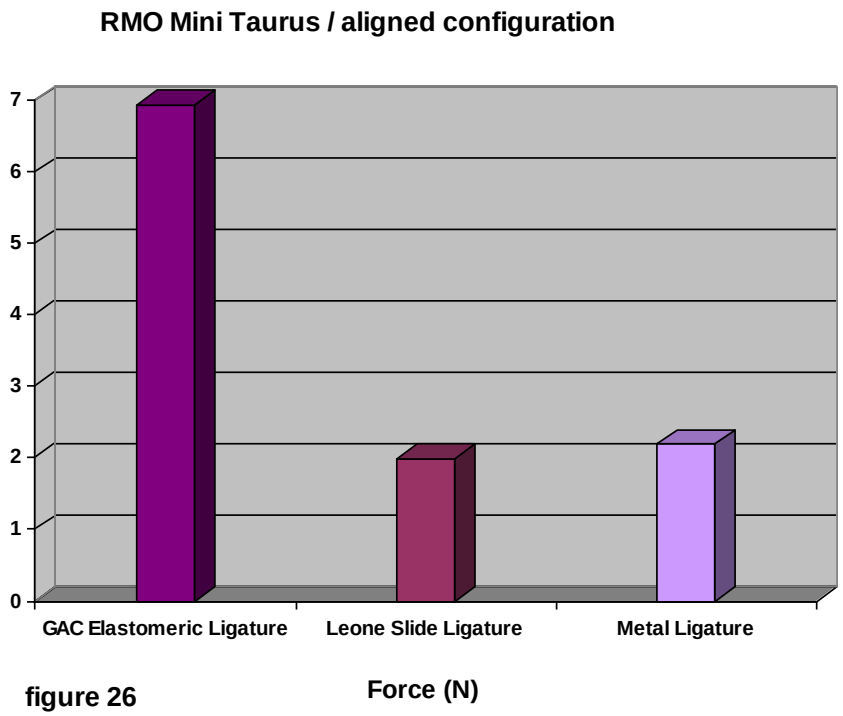


figure 26

6.2.3.4. RMO Signature lll

The mean frictional value of GAC ligation method was significantly higher than those of the Slide ligatures and Metal ligatures ($p<0.01$). The mean frictional value of Slide ligation method was significantly lower than that of the metal ligation method. ($p<0.01$) (Table17, 18, Fig. 27)

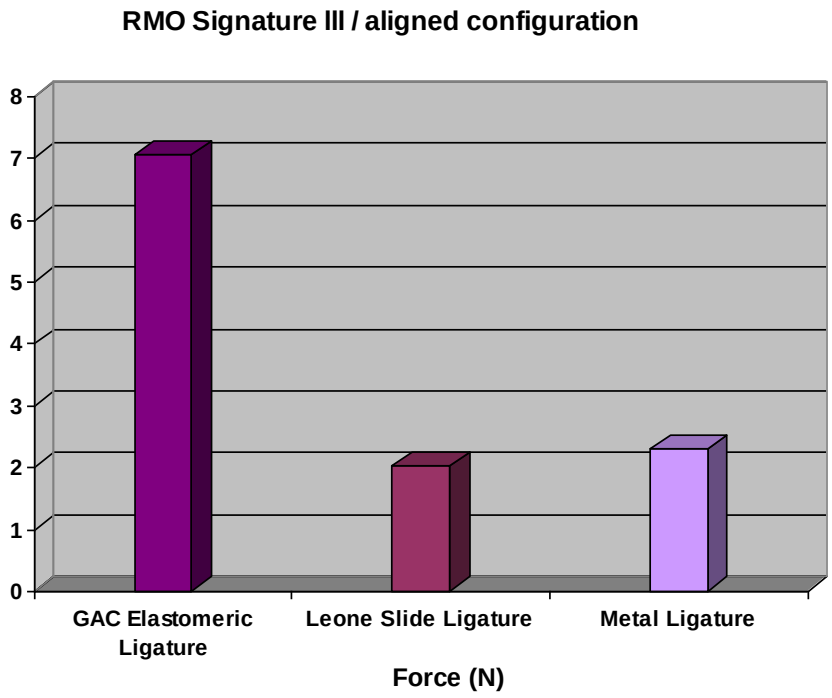


figure 27

6.2.4.. Evaluation of frictional values of self ligating brackets and conventional brackets ligated with different ligation methods at the aligned configuration

Table 19: Comparison of frictional values of self ligating brackets and conventional brackets ligated with GAC elastic ligatures. (aligned configuration)

Bracket / GAC elastics	Force-F (N) mean±SD	*p*
Clarity SL	**2,17±0,01**	***t:-126,484***
Leone Logic Line / GAC Elastic Ligature	**7,30±0,13**	***p:0,001*****
Clarity SL	**2,17±0,01**	***t:-75,938***
Inspire Ice/GAC Elastic Ligature	**8,28±0,25**	***p:0,001*****
Clarity SL	**2,17±0,01**	***t:-82,522***
RMO Mini Taurus/ GAC Elastic Ligature	**6,94±0,18**	***p:0,001*****
Clarity SL	**2,17±0,01**	***t:-198,650***
RMO Signature lll/ GAC Elastic Ligature	**7,05±0,08**	***p:0,001*****
Damon 3M	**1,99±0,003**	***t:-130,989***
Leone Logic Line / GAC Elastic Ligature	**7,30±0,13**	***p:0,001*****
Damon 3M	**1,99±0,003**	***t:-78,153***
Inspire Ice / GAC Elastic Ligature	**8,28±0,25**	***p:0,001*****
Damon 3M	**1,99±0,003**	***t:-85,624***
RMO Mini Taurus / GAC Elastic Ligature	**6,94±0,18**	***p:0,001*****
Damon 3M	**1,99±0,003**	***t:-206,503***
RMO Signature lll / GAC Elastic Ligature	**7,05±0,08**	***p:0,001*****
Innovation C	**2,13±0,01**	***t:-126,665***
Leone Logic Line / GAC Elastic Ligature	**7,30±0,13**	***p:0,001*****
Innovation C	**2,13±0,01**	***t:-76,298***
Inspire Ice / GAC Elastic Ligature	**8,28±0,25**	***p:0,001*****
Innovation C	**2,13±0,01**	***t:-82,940***
RMO Mini Taurus / GAC Elastic Ligature	**6,94±0,18**	***p:0,001*****
Innovation C	**2,13±0,01**	***t:-196,980***
RMO Signature lll / GAC Elastic Ligature	**7,05±0,08**	***p:0,001*****

t:Student t test ***** p<0.01***

6.2.4.1. Self ligating brackets and conventional brackets ligated with GAC elastomeric ligatures

6.2.4.1.A. Clarity SL / Conventional brackets ligated with GAC elastomeric ligatures

The mean frictional value of the Clarity SL brackets was significantly lower than Leone Logic Line brackets, Inspire ICE brackets, RMO Mini Taurus and RMO Signature brackets ligated with GAC elastic ligatures ($p<0.01$) (Table 19, Fig. 28).

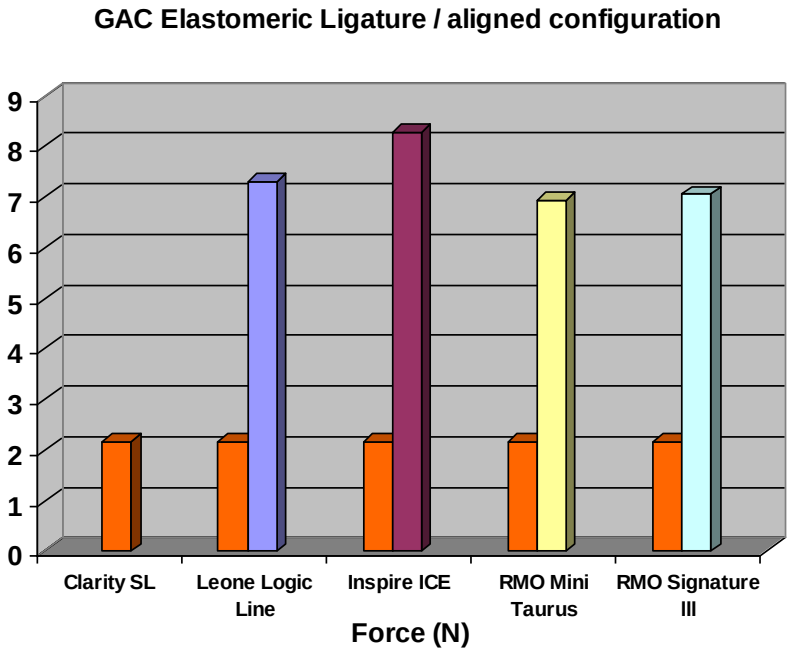


figure 28

6.2.4.1.B. Damon 3 / Conventional brackets ligated with GAC elastomeric ligatures

The mean frictional value of the Damon 3 brackets was significantly lower than Leone Logic Line brackets, Inspire Ice brackets, RMO Mini Taurus and RMO Signature brackets ligated with GAC elastic ligatures ($p<0.01$) (Table 19, Fig. 29).

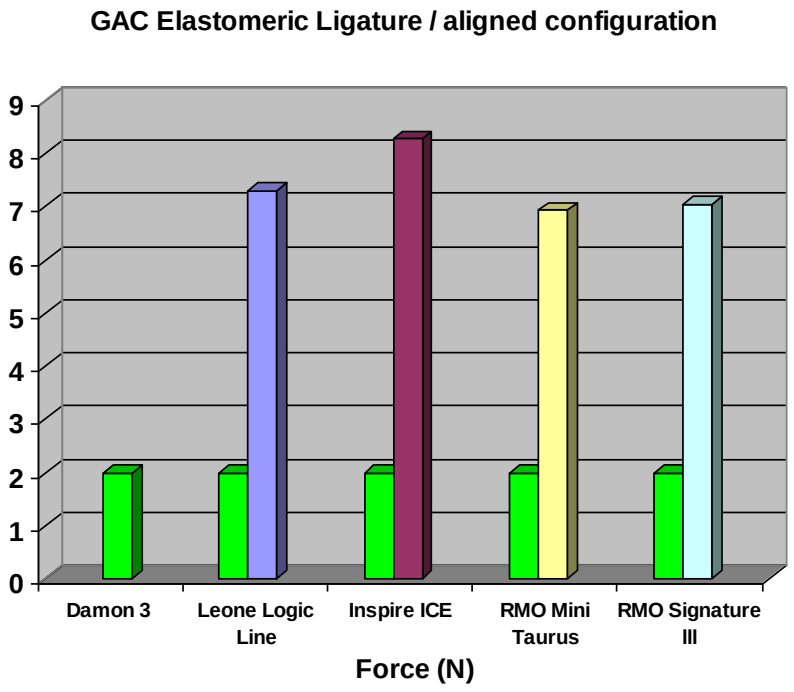


figure 29

6.2.4.1.C. Innovation C / Conventional brackets ligated with GAC elastomeric ligatures

The mean frictional value of the Innovation C brackets was significantly lower than Leone Logic Line brackets, Inspire Ice brackets, RMO Mini Taurus and RMO Signature brackets ligated with GAC elastic ligatures ($p<0.01$) (Table 19, Fig. 30).

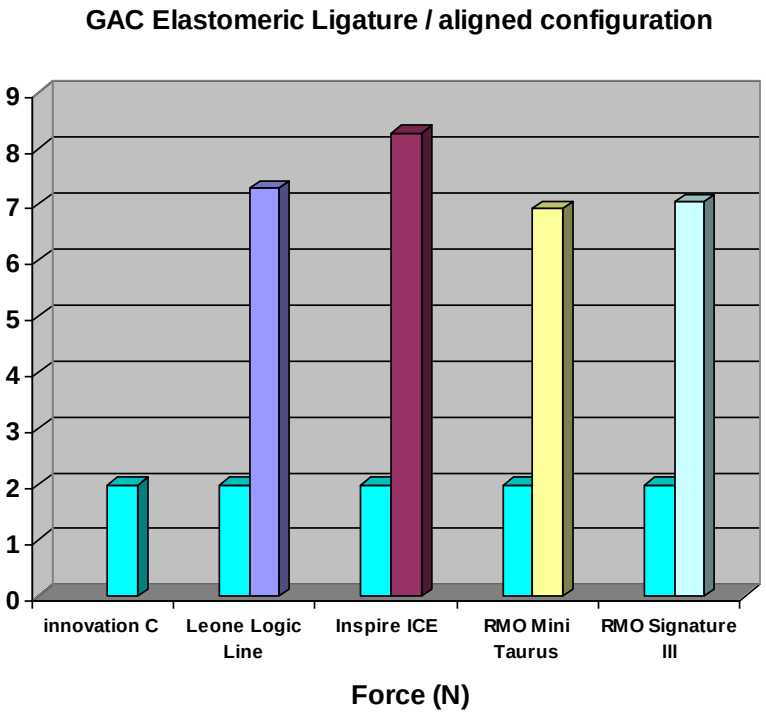


figure 30

Table 20: Comparison of frictional values of self ligating brackets and conventional brackets ligated with Leone Slide ligatures (aligned configuration)

Bracket / Leone Slide ligatures	Force-F (N) Mean ±SD	*p*
Clarity SL	**2,17±0,01**	***t:10,067***
Leone Logic Line / Leone Slide ligatures	**2,07±0,03**	***p:0,001*****
Clarity SL	**2,17±0,01**	***t:6,244***
Inspire Ice/ Leone Slide ligatures	**2,13±0,02**	***p:0,001*****
Clarity SL	**2,17±0,01**	***t:63,224***
RMO Mini Taurus/ Leone Slide ligatures	**1,99±0,01**	***p:0,001*****
Clarity SL	**2,17±0,01**	***t:46,151***
RMO Signature lll/ Leone Slide ligatures	**2,02±0,01**	***p:0,001*****
Damon 3	**1,99±0,003**	***t:-9,538***
Leone Logic Line / Leone Slide ligatures	**2,07±0,03**	***p:0,001*****
Damon 3	**1,99±0,003**	***t:-27,305***
Inspire Ice / Leone Slide ligatures	**2,13±0,02**	***p:0,001*****
Damon 3	**1,99±0,003**	***t:1,244***
RMO Mini Taurus / Leone Slide ligatures	**1,99±0,01**	***p:0,230***
Damon 3	**1,99±0,003**	***t:-11,492***
RMO Signature lll / Leone Slide ligatures	**2,02±0,01**	***p:0,001*****
Innovation C	**2,13±0,01**	***t:5,248***
Leone Logic Line / Leone Slide ligatures	**2,07±0,03**	***p:0,001*****
Innovation C	**2,13±0,01**	***t:-0,528***
Inspire Ice / Leone Slide ligatures	**2,13±0,02**	***p:0,604***
Innovation C	**2,13±0,01**	***t:26,571***
RMO Mini Taurus / Leone Slide ligatures	**1,99±0,01**	***p:0,001*****
Innovation C	**2,13±0,01**	***t:19,855***
RMO Signature lll / Leone Slide ligatures	**2,02±0,01**	***p:0,001*****

t:Student t test ***** p<0.01***

6.2.4.2. Self ligating brackets and conventional brackets ligated with Leone Slide ligatures

6.2.4.2. A. Clarity SL / Conventional brackets ligated with Leone Slide Ligatures

The mean frictional value of Clarity SL Brackets was significantly higher than Leone Logic Line brackets, Inspire Ice brackets, RMO Mini Taurus and RMO Signature brackets ligated with Leone Slide ligatures ($p<0.01$) (Table 20, Fig. 31) .

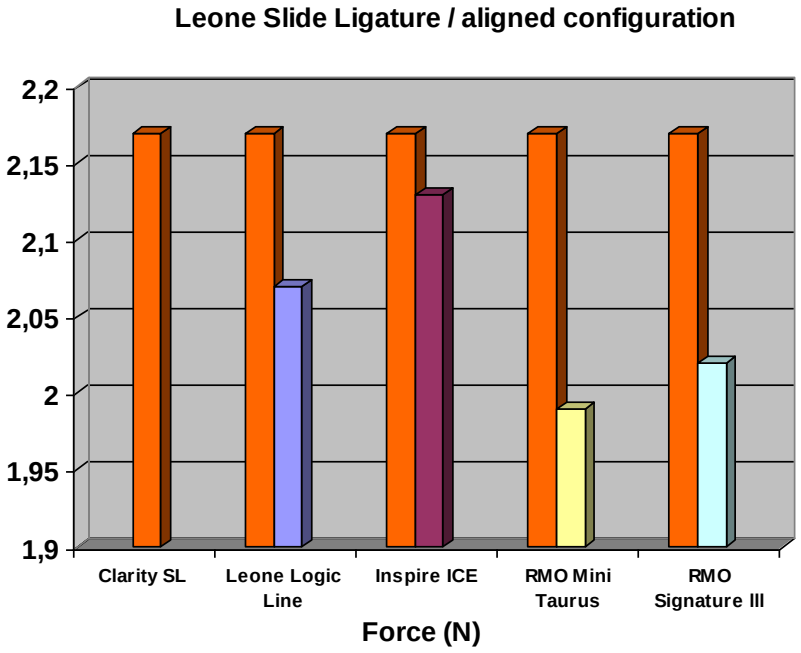


figure 31

6.2.4.2.B. Damon 3 / Conventional brackets ligated with Leone Slide ligatures

The mean frictional value of Damon 3 Brackets was significantly lower than Leone Logic Line brackets, Inspire Ice brackets and RMO Signature brackets ligated with Leone Slide ligatures ($p<0.01$). The difference between the mean frictional forces of Damon 3 brackets and RMO Mini Taurus brackets ligated with Leone Slide ligatures was statistically insignificant.($p>0.05$) (Table 20, Fig. 32).

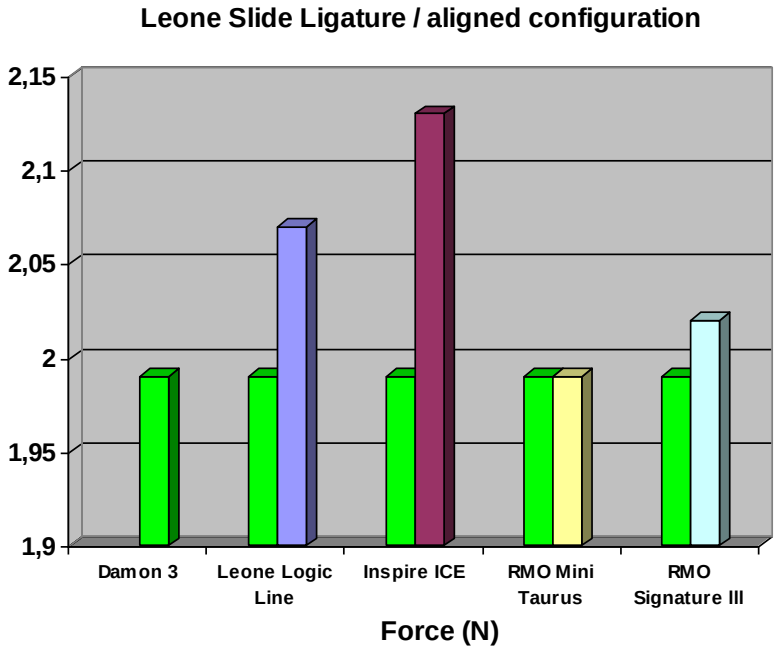

Leone Slide Ligature / aligned configuration
2,15
2,1
2,05
2
1,95
1,9
Damon 3
Leone Logic Line
Inspire ICE
RMO Mini Taurus
RMO Signature III
Force (N)

figure 32

6.2.4.2.C. Innovation C / Conventional brackets ligated with Leone Slide ligatures

The mean frictional value of Innovation C brackets was significantly higher than Leone Logic Line, RMO Mini Taurus and RMO Signature brackets ligated with Leone Slide ligatures ($p<0.01$). The difference between the mean frictional forces of Innovation C brackets and Inspire Ice brackets ligated with Leone Slide ligatures was statistically insignificant ($p>0.05$) (Table 20, Fig. 33).

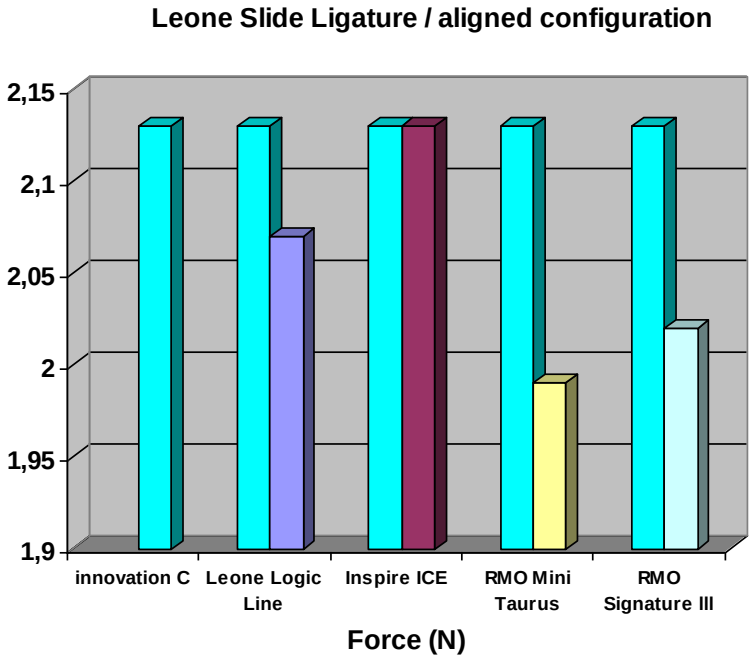


figure 33

Tablo 21: Comparison of frictional values of self ligating brackets and conventional brackets ligated with metal ligatures

Bracket / Metal ligatures	**Force-F (N)** **Ort±SD**	***p***
Clarity SL	**2,17±0,01**	***t:-26,120***
Leone Logic Line / Metal ligatures	**2,49±0,04**	***p:0,001*****
Clarity SL	**2,17±0,01**	***t:11,433***
Inspire Ice/ Metal ligatures	**2,10±0,02**	***p:0,001*****
Clarity SL	**2,17±0,01**	***t:-2,763***
RMO Mini Taurus/ Metal ligatures	**2,19±0,02**	***p:0,013****
Clarity SL	**2,17±0,01**	***t:-18,711***
RMO Signature lll/ Metal ligatures	**2,30±0,02**	***p:0,001*****
Damon 3	**1,99±0,003**	***t:-41,009***
Leone Logic Line / Metal ligatures	**2,49±0,04**	***p:0,001*****
Damon 3	**1,99±0,003**	***t:-18,686***
Inspire Ice / Metal ligatures	**2,10±0,02**	***p:0,001*****
Damon 3	**1,99±0,003**	***t:-32,118***
RMO Mini Taurus / Metal ligatures	**2,19±0,02**	***p:0,001*****
Damon 3	**1,99±0,003**	***t:-46,104***
RMO Signature lll / Metal ligatures	**2,30±0,02**	***p:0,001*****
Innovation C	**2,13±0,02**	***t:-27,487***
Leone Logic Line / Metal ligatures	**2,49±0,04**	***p:0,001*****
Innovation C	**2,13±0,02**	***t:4,100***
Inspire Ice / Metal ligatures	**2,10±0,02**	***p:0,001*****
Innovation C	**2,13±0,02**	***t:-7,206***
RMO Mini Taurus / Metal ligatures	**2,19±0,02**	***p:0,001*****
Innovation C	**2,13±0,02**	***t:-20,386***
RMO Signature lll / Metal ligatures	**2,30±0,02**	***p:0,001*****

t:Student t test ***** p<0.01***

6.2.4.3. Self ligating brackets and conventional brackets ligated with metal ligatures

6.2.4.3.A. Clarity SL / Conventional brackets ligated with metal ligatures

The mean frictional value of Clarity SL Brackets was significantly lower than Leone Logic Line brackets and RMO Mini Taurus brackets ligated with metal ligatures ($p<0.01$). The mean frictional value of Clarity SL brackets was significantly lower than RMO Signature bracket ligated with metal ligatures ($p<0.05$). The mean frictional value of Clarity SL brackets was significantly higher than Inspire Ice brackets ligated with metal ligatures ($p<0.01$) (Table 21, Fig. 34).

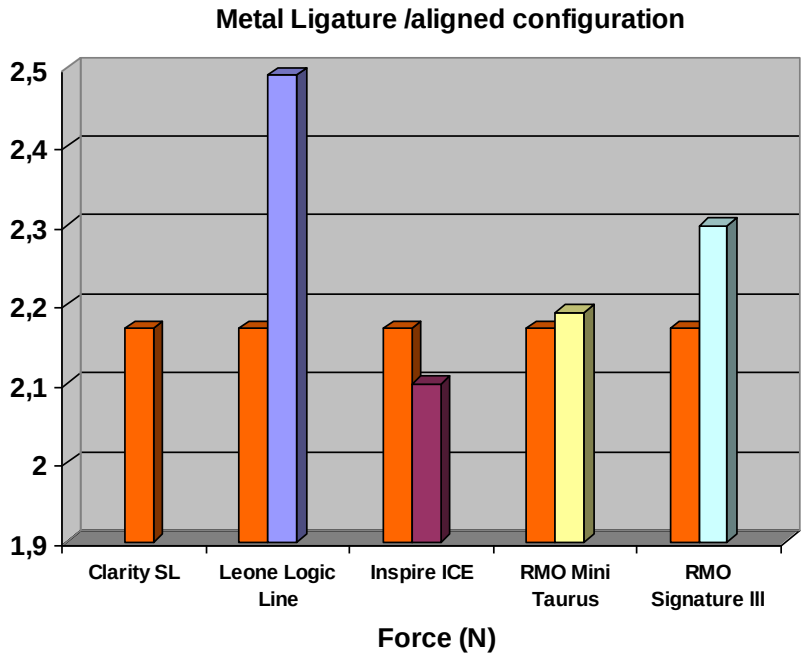


figure 34

6.2.4.3.B. Damon 3 / Conventional brackets ligated with metal ligatures

The mean frictional value of Damon 3 Brackets was significantly lower than Leone Logic Line brackets, Inspire Ice brackets, RMO Mini Taurus brackets and RMO Signature brackets ligated with metal ligatures ($p<0.01$) (Table 21, Fig. 35).

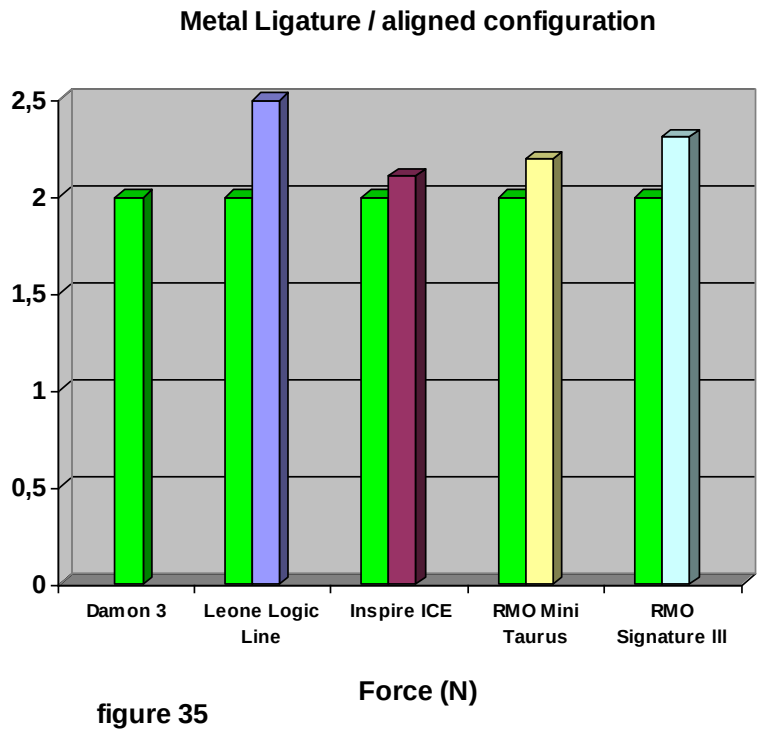


figure 35

6.2.4.3.C. Innovation C / Conventional brackets ligated with metal ligatures

The mean frictional value of Innovation C brackets was significantly lower than Leone Logic Line brackets, RMO Mini Taurus and RMO Signature brackets ligated with metal ligatures ($p<0.01$). The mean frictional value of Innovation C brackets was significantly higher than Inspire Ice brackets ligated with metal ligatures ($p<0.01$) (Table 21, Fig. 36).

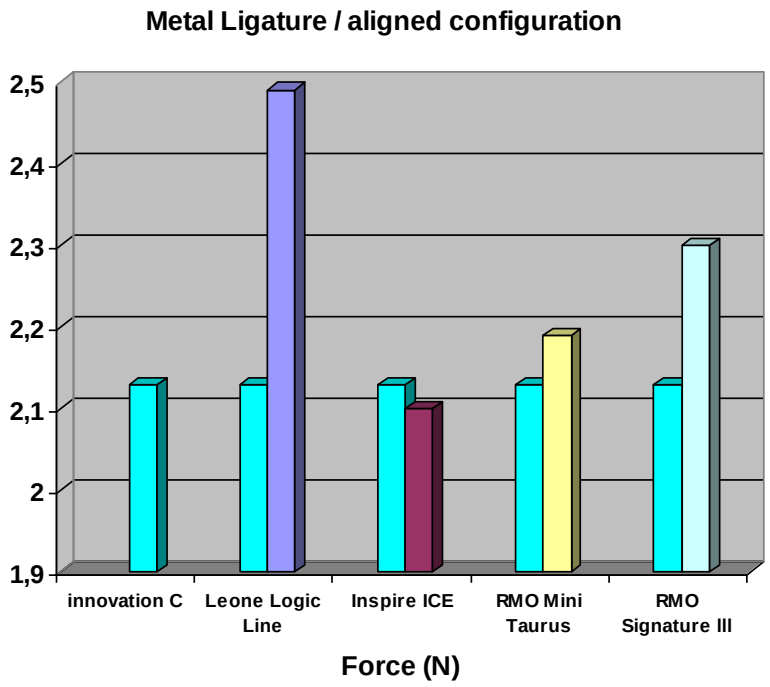


figure 36

7. DISCUSSION

7.1. Purpose

Two of the qualities most desired in the contemporary use of fixed appliances are good esthetics and low friction. In modern society, the esthetic aspect of orthodontic therapy is important because of the increasing numbers of adult patients. Ceramic brackets were developed to improve esthetics during orthodontic treatment. However, they tend to have high frictional resistance to sliding mechanics when compared with stainless steel brackets. Frictional forces can be reduced by means of either passive self-ligating brackets or low-friction ligatures. Even though esthetic self ligating brackets and low-friction ligatures are becoming popular, there is not enough study to evaluate frictional forces of these brackets in the literature. In 2003 Cacciafesta et al have compared the Oyster esthetic self ligating brackets with the self ligating metal brackets and conventional metal brackets (14). In another study in 2005 Tabakman have compared the Opal esthetic self ligating brackets to the Innovation R metal self ligating brackets, Mystique conventional ceramic brackets and Clarity esthetic conventional brackets (105). Franchi et al in 2008 have compared the Opal brackets to the brackets ligated with nonconventional elastomeric modules (27). However there is still need for further investigations about esthetic self ligating brackets and different ligation methods.

So the purpose of our study was to compare the frictional resistance of different brands of esthetic self ligating brackets to the conventional esthetic and metal brackets ligated with different methods at different stages of the treatment.

In our study, 3 different esthetic self ligating bracket brands were evaluated in terms of friction and compared to 3 different conventional esthetic and 1 conventional metal bracket brand each were ligated with 3 different methods. In that manner we believe that this study will be helpful to understand the frictional properties of the esthetic self ligating brackets more comprehensively.

7.2. Materials and Method

Innovation C, Clarity SL and Damon 3 esthetic self ligating brackets were tested in this study. These brackets are relatively new but popular at the market however there are not many studies related to them. Inspire ICE, RMO Signature lll

and Leone Logic Line brackets were selected as the conventional esthetic brackets due to their different structures from one another (Mono crystalline, Polycrystalline and Micro-filled copolymer). As a control group, conventional metal bracket RMO Mini Taurus bracket was selected because it is well known and widely used brackets.

Damon 3 brackets are the newer generation of Damon 2 self ligating brackets but the body of the bracket is covered with composite in order to improve the esthetics. It has a passive sliding clip which converts the bracket into a tube. Clarity SL brackets are also passive brackets. They have an open slot with 3 metal walls and have nitinol metal clips at the sides to hold the wire inside the slots. Innovation C brackets have inter-active clips which push the wire towards the base of the slot leading to increased frictional force values compared to passive ones.

In passive self ligating brackets, manufacturers aimed to keep the friction as low as possible at every stage of the treatment. They have rigid precision arms which do not extend into the slot and result in minimal seating of the arch wires however this approach brings some disadvantages like torque control. Active brackets are characterized by a precision arm which partially extends into slot and produces a low seating force on the arch wire at all times. In inter-active brackets, the clips act like passive brackets until reaching to a certain wire dimension or deformation. Brackets become active and start to put pressure on the arch wire following insertion of thicker wires which will lead to more friction. But this is favorable in the later stages of treatment in which the orthodontists deal with torque and uprighting movements. According to some researchers like Rinchuse DJ and Harradine NW, passive self ligating brackets have less rotational control compared to active ones (90, 34). In addition, Kusy et al and Cacciafesta et al claimed that passive self ligating brackets have less torque control since the arch wire were hold passively in the slot (14, 63). There are many studies which are comparing self ligating brackets to one another and to the conventional brackets but there are fewer literatures on esthetic self ligating brackets. Franchi et al in 2008 compared Damon 3 , Opal, Smartclip and Carriere passive self ligating brackets to one another and to the metal brackets which were conventionally and nonconventionally ligated (27). They found that there was no significant difference between the frictional resistances of Opal and Damon 3 brackets additionally they conclude that the Opal, Damon 3 and nonconventionally (Leone Slide) ligated metal brackets showed lower frictional resistance compared to conventionally ligated metal brackets. Kim et al in 2008 compared the passive self

ligating brackets Damon 2, Damon 3 and Smartclip to the active self ligating brackets Speed, In-Ovation and Time brackets. They developed a typodont which mimics the upper and lower jaws and used 0,014" and 0,016" Ni-Ti arch wires to perform the friction tests (51). They found that passive self ligating brackets exhibiting lower frictional resistance than active self ligating brackets. Griffiths et al in 2004 compared Damon 2 brackets to a mono crystalline and to a metal bracket. They found that mono crystalline brackets showed the highest and Damon 2 brackets showed the lowest frictional level (33). Tabakman in 2005 compared Opal esthetic self ligating bracket to the Innovation metal self ligating brackets, Mystique polycrystalline bracket, Inspire ICE mono crystalline brackets and Clarity metal slot esthetic brackets (105). He found that Opal showed the least friction and followed by Innovation, Clarity and Mystique brackets. Inspire ICE showed the highest frictional resistance.

In our study we used 0.014" nickel titanium arch wires in the crowded configuration of the bracket alignment because they are common used wires in the leveling phase of the orthodontic treatments. They are very flexible and have a large working range. For the second configuration which mimics the leveled phase of the treatment we have used 0.016" stainless steel wires. These wires are rigid enough and their surface features are appropriate for sliding mechanics (73, 33).

In our study all tests were performed in the dry conditions and at the room temperature. About the presence of the saliva there are conflicting results of different studies. West VC. et al, Baker KL, Kusy and Whitley found that the presence of the saliva decreases the friction (7,62). They explained it with the greasy effect of the saliva. In contradiction, Pratten DH and Stannard JG et al found that saliva was causing increased friction (82, 103). They claimed that an adhesion occurs between the arch wire and the bracket slot which is increasing the frictional resistance. Kusy et al found that saliva is causing decreased friction in ceramic brackets but increased friction in metal brackets. In addition they found that saliva is causing increased friction with stainless steel wires but almost 50% decreased friction in beta titanium wires. Griffiths et al reported a decrease with 0.018" stainless steel and an increase with 0.019"x0.025" stainless steel in wet conditions (33). Since the results related to the presence of the saliva are contradictory to each other, the tests in our study are performed in dry conditions.

The frictional forces have been measured with different types of equipments in different studies such as dynamometer, power pumps and universal testing devices. In

our study we used Zwick-Roell Z250 universal testing machine in Tubitak-UME in Gebze, Izmit. This device is similar to other universal testing devices which are used for pulling, grazing and tearing off tests such as Shimadzu AG-IS (Shimadzu Corp, Kyoto, Japan), Instron Machine (Instron Corporation, Canton, Mass), Lloyd 30K (Lloyd Instruments Ltd,Segensworth, Fareham, England), Emic DL 10000 (Sao Jose do Rio Preto, PR, Brazil), Tensometer 10 (Monsata plc, Swindon, UK) and Nene M3000 (Wellingborough, Northamptonshire, UK).

There are different types of test protocols to measure the frictional forces of the brackets and ligation methods. We can explain these methods in three groups. In the first method, the arch wire is parallel to the bracket slots with no angulation and torque and was pulled along the bracket slot. But this method is far apart from mimicking the biological and dynamical environment. In the second method there are some first, second and third order bends which will allow you to measure not only the ligational forces but also the bracket properties in terms of friction. And in the third method they designed a system which allows the teeth to move. In this last method there is a silicone model which mimics the biological movements of the teeth against the applied force and let the teeth to tip and rotate. Even though this method may sound better to mimic the oral conditions, it is not possible to receive the real respond of the periodontal ligament together with the occlusal forces.

Açıklama [DR1]: 2.9.21.41.55.

Açıklama [DR2]: 3,27,76,88,100

In our study, we choose to use second method because we aimed to reveal the frictional forces of various brackets in the crowded and well aligned situation and to find out the real performance of self ligating brackets by comparing them to the conventional ones. The brackets which are going to be tested were fixed on stainless steel plates. Redlich et al, Sims et al and Thomas et al used similar technique but they preferred aluminum metal plates (88, 99, 110). For the standardization of the bracket alignments in all samples a special designed jig 0.017”x0.025” SS wire was used as Sims et al and Thomas et al suggested. These jigs enabled us to provide the same bracket alignments in all tested bracket brands. Some researchers used cianoacrylate to fix the brackets on the metal plates however we preferred to use light curing composite as Bednar et al, Berger et al, Kapila and Kapur did in their studies because of the longer working time of composites (9, 10, 4, 42)

Açıklama [DR3]:

Açıklama [DR4]:

In our study, the pulling speed of the tests were 10 mm/min as Redlich et al did in their study in 2003.. In the literature there are many different protocols related to pulling speed. Some researches pulled with a speed of 10 mm/min and some with

Açıklama [DR5]: 3,73,78,99

5mm/min. On the other hand some researchers preferred relatively slow speed like 0.5 mm/min and 1 mm/min. Kusy and Whitley stated that increased pulling speed will result in vibration because of stick-slip phenomena on the other hand very slow speed will cause corrosive abrasion. Generally it is accepted that the pulling speed does not affect the results unless it is too fast or too slow. Ireland et al in 1991 made friction tests with a 0.5, 1, 5, 10, 20 and 50 mm/min speed and they found no statistically significant difference.

Açıklama [DR6]: 12,112

The tests were repeated 10 times for each sample. After each test a new arch wire was inserted. Kusy and Whitley have examined the brackets and the wires with SEM after friction tests and they found notching especially when there was torque and angulation at the system (59). Kapur et al have found increased friction values at the brackets which are tested for several times (43). Articolo et al stated that the most notching occurs in the lingual side of the arch wires which is touching to the base of bracket slot (4). Thus we preferred to change the arch wires for each sample however we did not change the brackets because in the patient's mouth it is not possible to change the brackets throughout the treatment with every new wire insertion. Additionally the notching at the brackets would be the same for all the tested brands.

Açıklama [DR7]: 3,5,7,9,50,78

In our study, we measured both the static frictional values and the kinetic frictional values at 5th, 10th and 15th seconds. The results were recorded with a software named Test-expert and showed in a two dimensional X-Y graphic. The static frictional value was accepted as the maximum value at the start of the test as Bacetti, Baker, Dowling and Frank did in their studies (6, 7, 19). Omana et al stated that the teeth are moving along the arch wires with small tippings and uprightings more than a continuous movement. Frank and Nikolai stated that there will be both static and kinetic friction during the movement of the arch wire (28). Hain et al evaluated the friction of the teeth in two stages. They claimed that static friction is the resistance against the first movement of the teeth and than once the movement starts, static friction switches into a kinetic friction. Redlich et al stated that kinetic friction is effective during the movement of the teeth but static friction is more reliable for determining the force level of the system (88). The studies which evaluated static and kinetic friction together claimed that the difference between these two force levels were not statistically significant.

Açıklama [DR8]: 13,14,84,21

Most of the studies related to the friction values of the brackets were done in vitro and could not be able to present the natural clinical situation. Some researchers

tried to develop their in vitro study models to mimic the clinical situation. Drescher et al fixed the brackets on the metal plates and than embedded this plates in an elastic sponge in order to have a 3 dimensional movement as it is in the mouth (22). Loftus et al have created an acrylic tooth socket filled with some polyvinylcylocsan impression material to mimic the periodontal ligament. They stated that this material allows the teeth to tip and rotate as it happens in the mouth. They used 0.022" slot brackets and an Instron machine to perform the tests which takes 4 minutes for each sample. They found statistically no significant difference among the conventional metal brackets, self-ligating metal brackets and metal slot ceramic brackets. They claimed that the tipping and rotations occurred at the system caused an extra friction in the slots. However the frictional resistance of the conventional ceramic brackets was significantly higher than the other samples. They think that the reasons were higher frictional coefficient and increased surface roughness of the ceramic brackets. Loftus et al also stated that this testing protocol could not exactly mimic all the oral conditions such as occlusal forces, presence of the saliva and parafunctional habits.

7.3. Results

The subject of our study was to thoroughly examine the frictional values of different brackets and ligation methods at different situations. So we did a comprehensive study and achieved a large variety of results. To make it easier to understand, we decided to discuss the findings in five subtitles

1- Comparison of frictional values of different ligation methods free of bracket brands

2- Comparison of the frictional values of conventional brackets ligated with different methods

3- Comparison of the frictional values of self ligating brackets

4- Comparison of the frictional values of the self ligating brackets and conventional brackets ligated with GAC elastomeric and metal ligatures

5- Comparison of the frictional values of the self ligating brackets and nonconventionally (Leone Slide ligatures) ligated conventional brackets

7.3.1. Comparison of frictional values of different ligation methods free of bracket brands

In this study one of our aims was to compare the frictional values of different conventional (elastomeric ligature and metal ligature) and nonconventional (Slide ligature) ligating methods free of bracket brands. We found that both in aligned and crowded configurations Leone Slide ligatures produced the lowest frictional values compared to other ligation methods.

Bacetti and Franchi did an in vitro study in 2006 on a buccal segment model (6). They compared Slide Ligatures (Leone) and conventional elastomeric ligatures in dry conditions. In the study they used 0,022 “slot brackets combined with 0,019” x 0,025” SS and 0,014” Ni-Ti wires. Similar to our study they found that in both archwires Slide ligatures showed lower frictional resistance compared to elastomeric ligatures. Fortini et al did a study about the Slide ligatures (Leone Orthodontic Products) in 2005 (26). In their in vivo study they found that Slide ligatures

decreased the frictional value in the leveling stage and shortened the treatment time. Tabakoglu and Arun compared in their study Slide, Super Slick, Versa Tie, Alastik elastomeric ligatures, Teflon coated stainless steel ligatures and stainless steel ligatures (106). They found that Slide ligatures showed significantly lower frictional forces compared to other elastomeric ligating methods. Our results are parallel with the literatures about non conventional ligating methods. We believe that since the Slide ligatures convert the brackets into tubes and make no active pressure on the archwires, they show significantly lower frictional values.

GAC elastomeric ligatures showed significantly higher frictional resistance compared to metal ligatures in aligned configuration ($p< 0.01$) but lower frictional resistance in crowded configuration ($p>0.05$). We think for the aligned configuration; because elastomeric ligatures were pressing to the archwire at the sides of the brackets they create an extra friction at the system on the other hand metal ligatures were considerably passive because they were squeezed at the sides of the brackets which probably resulted in a lowered frictional value. In crowded configuration, the elastomeric ligatures were causing lesser binding at the archwire because they were more flexible and this caused lower friction.

Echols in 1975 in his study found that elastomeric ligatures resulting in increased friction in sliding mechanics. Besides he added that as the dimension of the arch wires increases the friction increases (23). Berger in 1990 compared the frictional resistance of stainless steel ligatures and elastomeric ligatures with the metal and ceramic brackets (10). He found that the frictional resistance of metal ligatures was lower than the elastomeric ones. Bednar in 1995 and Voudouris in 1997 found that the frictional resistance of stainless steel ligatures was lower than the elastomeric ligatures (9,115). Khambay et al compared the frictional resistance of the stainless steel ligatures (3M Unitek), Alastik elastomeric ligatures (3M Unitek) and Superslick elastomeric ligatures (TP Orthodontics) in 2005 (50). They claimed that stainless steel ligatures showed the least frictional force. Bazakidou et al did an in vitro study with elastomeric ligatures and stainless steel ligatures in dry conditions in 1997 (8). They stated that it is not possible to say one of them have more frictional resistance but they added that the frictional resistance of the stainless steel ligatures can change up to 3 times more than elastomeric ligatures. Sims et al (1993) found no significant result in frictional resistance when conventionally tied elastomeric ligatures were compared with stainless steel ligatures tightened with 7 turns (99). But he demonstrated that

tying elastomeric ligatures in a figure eight pattern around identical brackets raised the frictional resistance 70-220 percent depending on the wire dimensions. He also reported that larger wires led to a greater increase in friction compared to smaller wires.

7.3.2. Comparison of the frictional values of conventional brackets ligated with different ligation methods

7.3.2.1 GAC Elastomeric ligature

A: At the aligned configuration

Significant differences were found between the groups when all conventional brackets were ligated with GAC elastomeric ligatures at the aligned configuration. The only nonsignificant difference was found between Mini Taurus and Signature lll brackets which they showed lowest frictional values compared to others. Inspire ICE brackets showed the highest frictional resistance.

B: At the crowded configuration

Significant differences were found between the groups. Leone Logic Line brackets showed the least frictional resistance which was followed by RMO Mini Taurus, RMO Signature lll brackets. Inspire ICE brackets showed the highest frictional resistance.

De Franco et al (1995) found single crystal alumina brackets tended to be lower in friction than polycrystalline brackets (17). Saunders and Kusy (1994) showed by scanning electron microscopy (SEM) that mono crystalline alumina brackets were smoother than polycrystalline brackets, but found no difference in frictional characteristics (95). On the other hand, Omana et al (1992) stated that the polycrystalline injection molded ceramic brackets were smoother and this created less friction than other ceramic brackets (75). Our results resemble with Omana's study since we measured highest frictional values with Inspire ICE brackets which is a mono crystalline alumina bracket. Tselepsis stated that recently introduced composite brackets with and without metal slots faired better in friction studies (112). Bazakidou et al (1997) found these newer composite brackets to have lower frictional resistance

than both ceramic and stainless steel brackets. We also found lower frictional values with Leone Logic Line brackets which is a composite bracket.

7.3.2.2. Metal ligature

A: At the aligned configuration

Statistically significant differences were found between the brackets ligated with metal ligatures even though the differences between the friction values were very little. The maximum frictional values were of Leone Logic Line brackets which were followed by RMO Signature lll, RMO Mini Taurus and Inspire ICE brackets.

B: At the crowded configuration

Significant differences were found between the brackets when ligated with metal ligature at the crowded configuration. The maximum frictional values were of Inspire ICE which was followed by RMO Signature lll, RMO Mini Taurus and Leone Logic Line brackets. The values of Inspire ICE and RMO Signature lll brackets were almost twice as Leone Logic Line.

These results are generally identical with other studies but there are some irregularities about the metal ligation method. This can be explained due to the difficulties to standardize the metal ligation force. Bazakidou et al (1997) found no significant trend for friction with either elastomeric or steel ligation (8). Yet there was up to three times greater variability in friction with stainless steel ligation than elastomeric ligation, even though it was attempted to standardize both methods of ligation. Similarly Nanda in 1997 reported that the force of ligation of stainless steel ligatures can range from 50 to 300 gram (72).

Articolo et al (1999) found stainless steel brackets to have less friction than their ceramic counterparts in the passive configuration, which agrees with the study of Kusy and Whitley (1990) (3, 54). However, in the active configuration, when resistance to sliding is the product of friction and binding, stainless steel brackets were found less efficient than ceramic brackets.

Leone Logic Line brackets showed highest frictional resistance when ligated with metal ligatures at the aligned configuration. This result is similar to the Riley's study. He found that plastic brackets have shown higher frictional resistances than

stainless steel brackets when ligated with metal ligatures (89, 112). However Riley thought that this was resulted from deformation of the plastic brackets due to tightening of the steel ligatures which lead to compression of the slot and binding of the wire which we agree with the author about this statement. We also explain these higher values due to the difficulties of standardizing the tightening of the stainless steel ligatures. On the other hand Leone Logic Line brackets showed lowest frictional resistance at the crowded configuration. Bazakidou et al (1997) found these newer composite brackets to have lower frictional resistance than both ceramic and stainless steel brackets (8). Similarly Tselepsis stated that these brackets are showing better frictional values in new generation with or without metal slots. The results of our study are also supporting these statements (112).

In our study Inspire ICE brackets presented highest frictional values at the crowded configuration but lowest values in the aligned configuration. In the literature there are conflicting results related to the frictional values of mono crystalline brackets. Tabakman in 2005 compared Mystique polycrystalline bracket, Inspire ICE mono crystalline brackets, Opal ceramic brackets, Innovation brackets and Clarity metal slot esthetic brackets (105). He found that Opal showed the least friction and followed by Innovation, Clarity and Mystique brackets. Inspire ICE showed the highest frictional resistance.

As was mentioned, De Franco et al (1995) found mono crystalline brackets tended to be lower in friction than polycrystalline brackets (17). While Omana et al (1992) stated that the polycrystalline injection molded ceramic brackets were smoother and this created less friction than other ceramic brackets (75). On the other hand Saunders and Kusy (1994) showed by scanning electron microscopy (SEM) that mono crystalline alumina brackets were smoother than polycrystalline brackets, but found no difference in frictional characteristics (95).

RMO Mini Taurus presented lower frictional values than RMO signature lll brackets in both configurations which is matching with the literature. Griffiths et al in 2004 compared a mono crystalline bracket to a metal bracket (33). They found that metal bracket showed the lower frictional resistance. This result is attributed due to smoother surface of stainless steel brackets. The manufacturing process and bracket design may influence the frictional characteristics of orthodontic brackets

7.3.2.3. Slide ligature

A: At the aligned configuration

Significant differences were found between the brackets when ligated with Slide ligatures even though the differences between the friction values were very little. The maximum frictional values were of Inspire ICE brackets which were followed by Leone Logic Line, RMO Signature lll and RMO Mini Taurus brackets.

B: At the crowded configuration

Significant differences were found between the brackets when ligated with Slide ligatures at the crowded configuration. The maximum frictional values were of Inspire ICE which was followed by RMO Mini Taurus, RMO Signature lll brackets. Leone Logic Line brackets showed the least frictional values.

It is generally accepted that mono crystalline brackets have smoother slot surface compared to polycrystalline brackets on the other hand in terms of friction there are conflicting results. While De Franco claims that mono crystalline brackets showing lower frictional values, Omana claims the opposite (17, 75). Similarly, in our tests we also found that the Inspire ICE brackets showed the highest friction. Yuzbas and Arun found no significant difference between the Inspire ICE and Transcend (polycrystalline) brackets in terms of friction (119). Kusy commented that the frictional resistance of ceramic brackets is independent of their surface roughness. He added that it is likely related to their intrinsic chemical structure which is consisted of metal and ametal ions (53).

We found that in the aligned configuration Mini Taurus brackets showed lower friction level where as in the crowded configuration higher friction level compared to Signature lll brackets. In the literature, Nishio et al, Cacciafesta et al, Thortenson et al found that polycrystalline brackets showed higher frictional resistance than stainless steel brackets on the other hand Ireland et al, Downing et al and Rajakulendran et al found the opposite (74, 14, 111, 37, 21, 86). However, in the active configuration, when resistance to sliding is the product of friction and binding, stainless steel brackets showed higher frictional level than ceramic brackets.

Leone Logic Line brackets showed the least frictional resistance. This result is in harmony with the studies of Bazakidou et al and Tselepsis. They both claimed that

newer composite brackets were showing lesser frictional forces compared to stainless steel and ceramic brackets (8, 112).

7.3.3. Comparison of the frictional values of self ligating brackets

A: At the aligned configuration

Even though the frictional values were very close, comparison of groups revealed significant results. The mean frictional value of the Clarity SL brackets were higher than the Damon 3 and Innovation C brackets at the aligned configuration.

B: At the crowded configuration

At the crowded configuration the mean frictional value of the innovation C brackets were significantly higher than Damon 3 and Clarity SL. Damon 3 brackets showed the least frictional resistance in both configurations but the difference at the crowded configuration between Damon 3 and Clarity SL was insignificant.

Damon 3 and Clarity SL brackets are passive brackets. The manufacturer claims that Innovation C brackets are also passive until inserting a 0,018 inch width arch wires. So at the aligned configuration all 3 self-ligating brackets should be acting as passive brackets.

Innovation C brackets showed significantly higher frictional force at the crowded configuration. This may be due to its inter-active clip design which was reported to exert more pressure on the arch wire in the crowded situation. Additionally we can relate this result to its cobalt-chromium structured clip because the friction between Co-Cr clip and Ni-Ti wire is higher than that of the friction between SS clip and Ni-Ti wire as was reported by Kusy et al and Prososki et al (54, 83). Plus the other two samples had stainless steel slot where as Innovation C had a ceramic slot which is reported to cause higher frictional values as was mentioned above.

Using a buccal segment model, Taylor and Ison (1994) reported similar findings with passive self-ligating brackets (109). These passive brackets had significantly less frictional resistance than self-ligating brackets with an active spring-clip and conventionally tied brackets. Thortenson and Kusy (2002) determined that

brackets with active clips produced frictional forces as great as 50 times that of the brackets with passively ligating clips (111).

To improve the sliding performance of ceramic brackets, metal inserts have been placed in the slots to reduce friction. Loftus et al (1999) found that Clarity ceramic brackets with a metal slot insert (Unitek Corp., Monrovia, CA) have the same results as conventional stainless steel brackets in friction tests which is also supported by our findings. Sims et al (1993) noted that self-ligating brackets without an active spring clip had about fifteen times less frictional resistance than self-ligating brackets with an active spring clip (99).

7.3.4. Comparison of the frictional values of the self ligating brackets and conventional brackets ligated with GAC elastomeric and metal ligatures

7.3.4.1. GAC elastomeric ligature

A: At the aligned configuration

Comparison of all self ligating brackets with conventional brackets ligated with GAC elastomeric ligatures revealed significant differences in all combinations. All 3 self ligating brackets showed significantly lower frictional resistance compared to the conventional brackets ligated with GAC elastomeric ligatures.

B: At the crowded configuration

Comparison of all self ligating brackets with conventional brackets ligated with GAC elastomeric ligatures revealed significant differences except the comparisons of Clarity SL- Leone Logic Line, Damon 3-Leone Logic Line and Innovation C- RMO-Mini Taurus combinations.

Clarity SL, Damon 3 and Leone Logic Line brackets showed significantly lower frictional resistance than all brackets. Inspire ICE brackets showed highest frictional values followed by RMO Signature lll, Innovation C and RMO Mini Taurus.

7.3.4.2. Metal ligature

A: At the aligned configuration

Comparison of all self ligating brackets with conventional brackets ligated with metal ligatures revealed significant differences in all combinations. All 3 self ligating brackets showed significantly lower frictional resistance compared to the conventional brackets ligated with metal ligatures except Inspire ICE. Clarity SL brackets showed higher frictional resistance compared to Inspire ICE. Damon 3 brackets showed lower frictional resistance compared to all brackets. The frictional resistance of Inspire ICE ligated with metal ligatures was surprisingly lower than Clarity SL and Innovation C but still higher than Damon 3 brackets.

B: At the crowded configuration

Comparison of all self ligating brackets with conventional brackets ligated with metal ligatures revealed significant differences except the comparisons of Clarity SL - Leone Logic Line, Damon 3-Leone Logic Line and Innovation C- RMO Mini Taurus combinations.

Clarity SL and Damon 3 brackets showed significantly lower frictional resistance than conventional brackets except Leone Logic Line. Inspire ICE brackets showed highest frictional level among all brackets. Innovation C brackets showed higher frictional resistance than conventionally ligated Leone Logic Line brackets but lower frictional resistance than Inspire ICE and RMO Signature lll brackets. There was no significant difference between the conventionally ligated RMO Metal brackets and Innovation C self ligating brackets.

Thomas et al (1998) and Kapur et al (1998) found that self-ligating brackets produced less friction than elastomerically-tied conventional edgewise brackets (110, 42). These self-ligating brackets did not exert pressure on the arch wires. Sims et al (1993) also found self-ligating brackets had less frictional resistance than conventionally tied brackets (99). In contrast, Bednar et al (1991) testing self-ligating brackets with an active spring clip and Loftus et al (1999) testing self-ligating brackets with a passive spring clip found these bracket types performed no better than conventional stainless steel brackets ligated by either elastomers or steel ties in friction tests (9). These results might have been occurred due to their method which allows the teeth to tip during experiment.

Read-Ward et al (1997) compared various self-ligating brackets with conventional brackets (87). Results revealed that self-ligating brackets had lower frictional resistance in the passive configuration, but frictional resistance increased for

the self-ligating brackets as second order angulation increased. Sims et al (1994) reported that increasing angulation between the bracket and the archwire had a more profound effect on self-ligating brackets than conventional brackets, but they still produced less friction (99). Pizzoni et al (1998) found self ligating brackets to have less friction at all angulations than conventional brackets (80). Shivapuja and Berger (1994) found self-ligating brackets with both active and passive spring clips displayed significantly lower level of friction than conventional stainless steel and ceramic brackets (98). Our findings with conventionally ligated brackets are similar with these studies in the aligned configuration with the exception of Inspire ICE brackets ligated with metal ligatures resulted with lower frictional values than other brackets. This result can be explained by the difficulties of the standardization of ligation forces with metal ligatures. On the other hand, in crowded configuration Leone Logic Line brackets showed significantly lower frictional resistance than the active self ligating bracket Innovation C and showed no significant difference with Passive self ligating brackets Damon 3 and Clarity SL. These results are parallel with the studies of Bazakidou et al and Tselepsis et al. Both claimed that newer composite brackets were showing lesser frictional forces.

7.3.5. Discussion of the frictional values of the self ligating brackets and nonconventionally (Leone Slide ligatures) ligated conventional brackets

A: At the aligned configuration

Clarity SL brackets showed higher frictional resistance compared to conventional brackets ligated with Leone Slide ligatures. Damon 3 and RMO Mini Taurus brackets ligated with Leone Slide ligatures showed the lowest frictional resistance. Innovation C brackets showed higher frictional resistance compared to conventional brackets ligated with Leone Slide ligatures except Inspire ICE. Inspire ICE and Innovation C brackets showed the highest frictional resistance. Even tough it seems that there are significant differences between one another, all the results were close and varying between 1,99 and 2,17 N. So it is very difficult to reach a conclusion with these results at the aligned configuration.

B: At the crowded configuration

Leone Logic Line brackets ligated with Slide ligature showed the least frictional resistance.. Innovation C brackets showed the highest frictional resistance among the test group. Clarity SL and Damon 3 brackets also showed higher frictional resistance compared to conventional brackets ligated with Leone Slide ligatures except Inspire ICE brackets.

In the crowded configuration, Innovation C brackets showed higher frictional level due to its inter-active clip design and ceramic bracket slot. Conventional brackets ligated with Leone Slide ligatures showed lower frictional values due to the design of the Slide ligature which converts the brackets in to a tube. Additionally Leone Slide ligatures were causing less binding at the arch wire due to its elasticity at the crowded configuration. These results are parallel with the in vitro studies of Bacetti and Franchi in 2006 and Tabakoglu and Arun in 2007 (6, 106). Fortini et al in 2005 also found in their in vivo study that Slide ligatures decreased the frictional value in the leveling stage and shortened the treatment time (26).

8. CONCLUSION

1- The method in this study can not completely resemble the oral environment so the frictional values could not be presenting the real conditions however they can give us an idea about the frictional behaviors of the tested samples.

2- Our study revealed that the bracket material, ligation type and crowding all effect the frictional resistance.

3- In the aligned configuration, Leone Slide Ligature caused the least and GAC Elastomeric ligature caused the highest frictional resistance among the ligation methods however the difference between the metal ligation and elastomeric ligation disappeared when there was crowding.

4- Monocrystalline ceramic (Inspire ICE) brackets showed the highest frictional resistance at most of the friction tests.

5- RMO Signature lll ceramic brackets showed higher frictional resistance than RMO Mini Taurus metal brackets but the differences were very little. Only exception was at the crowded configuration with the slide ligatures.

6- Leone Logic Line composite brackets showed significantly lower frictional resistance compared to other conventional brackets with all ligation methods at the crowded configuration.

7- Passive self ligating brackets mostly revealed significantly lower frictional resistance compared to conventionally ligated brackets. Among them Damon 3 brackets showed the least frictional resistance.

8- Passive self ligating brackets revealed significantly lower frictional resistance compared to active one while the difference disappeared when there was no crowding.

9- Conventional brackets ligated with Leone Slide ligatures revealed similar frictional resistance with passive self ligating brackets and lower frictional resistance than active self ligating brackets.

10- Leone Logic Line-Leone Slide ligature combination revealed the least frictional resistance of all tests at the crowding configuration.

11- In terms of friction, passive esthetic self ligating brackets, composite brackets and nonconventional ligating method (Slide) could be recommended for clinical use according to the findings of this study.

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İngilizce	Çok iyi	Çok iyi	Çok iyi
Almanca	İyi	İyi	iyi

Yabancı Dil Sınav Notu #								
KPDS	ÜDS	IELTS	TOEFL IBT	TOEFL PBT	TOEFL CBT	FCE	CAE	CPE
					240			

	Sayısal	**Eşit Ağırlık**	**Sözel**
LES Puanı			
(Diğer) Puanı			

Bilgisayar Bilgisi

Program	**Kullanma becerisi**
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